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Glaciation in the Great Basin of the Western United States

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Abstract

Forty individually named ranges, plateaus, and massifs draining wholly or partly into the Great Basin of the western United States show definite evidence of Pleistocene glaciation. The most obvious deposits are a family of moraines designated, among other names, "Tioga", "Angel Lake", and "Pinedale". Such moraines generally can be traced from range to range away from described type moraines. These deposits have been numerically assigned to Late Wisconsinan glaciation in the Wasatch Range, White Mountains, Boulder Mountain, and Sierra Nevada on the basis of radiocarbon and surface-exposure ages, and have been assigned to Late Wisconsinan time in several other ranges on the basis of relative-age studies. The type Angel Lake moraine, and most other equivalent moraines across the Great Basin, are thick, hummocky, lobate piles of till rather than looping ridges. The thicknesses of the moraines (often 60 + m) can be explained by heavy debris loads, and/or glacial advance, retreat, and readvance to the same positions a number of times, which is consistent with recent evidence that multiple Late Wisconsinan advances, possibly related to Heinrich and Dansgaard-Oeschger events, occurred in the Sierra Nevada. Pre-Angel Lake deposits occur in many Great Basin ranges, but it is currently difficult or perhaps impossible to determine if these deposits are equivalent to each other and what their relationship is to pre-Tioga deposits in the Sierra Nevada. Numerical ages are rare and relative-age studies suggest that pre-Angel Lake deposits may be products of more than one glaciation. Mapped pre-Angel Lake glaciers were longer than their Angel Lake counterparts, but the length differences do not translate into large differences in ELA depression. There is evidence of two minor latest Pleistocene or early Holocene advances in some ranges, judging from the presence of overlying Mazama tephra and/or weathering comparisons to local Angel Lake moraines. In the latter part of the Holocene, ELA's were sufficiently high that only the highest, wettest ranges developed Neoglacial glaciers. There does not appear to be a consistent pattern of latest Pleistocene/Holocene glacial fluctuations along an east–west transect through the Cordillera, or even through the Great Basin.

1. Introduction

With regard to distribution of glacial deposits and history of glaciation, the Great Basin of the western United States has largely remained a blank spot on the map. The glacial histories of many of the ranges between the Sierra Nevada of California and the Wasatch Mountains of Utah have remained as obscure as they were in 1934, when Blackwelder published the results of a brief reconnaisance of the region. In other cases, some observations made in particular ranges have appeared only in theses and government publications that are not easily accessible. We have spent the last several years surveying deposits in the Great Basin, and between us have visited nearly all of the glaciated ranges listed in Table 1 and shown on Fig. 1. In this paper we draw together a bibliography of all relevant work known to us, and describe, and where possible, correlate the deposits we have observed in the field and on aerial photographs. The goal is to provide a regional summary and to relate deposits in the interior of the Great Basin to better-known deposits in the Sierra Nevada and Wasatch Ranges, hopefully to provide a springboard for future, more detailed research in individual ranges. Such research hopefully will include cosmogenic or other numerical dating of deposits; the lack of such dates at the time of writing precludes testing of climatic models or correlation with lake-sediment records.

Considering the area covered in this paper, not all features mentioned can be illustrated on maps. Included maps show representative, or particularly interesting, or particularly well-defined morainal positions in selected ranges. But all geographic features referred to in the text can be found on the relevant 1 : 24,000 scale US Geological Survey topographic maps. Topographic map sheets used as bases for map figures are listed in figure captions.

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Table 1
Glaciated ranges draining wholly or partly into the Great Basin[a]

Ruby Mountains/East Humboldt Range	
RM	Ruby Mountains
EHR	East Humboldt Range
Central Nevada Ranges	
TR	Toiyabe Range
TQR	Toquima Range
MR	Monitor Range
SW Great Basin Ranges	
SWN	Sweetwater Mountains
WM	White Mountains
SPM	Spring Mountains (?)
Sierra Nevada	
SN	Sierra Nevada
CR	Carson Range
NE California/NW Nevada Ranges	
PFR	Pine Forest Range
SRM	Santa Rosa Mountains
WAM	Warner Mountains
S-Central Oregon Ranges	
DP	Drakes Peak
HM	Hart Mountain
GM	Gearhart Mountain
YM	Yamsey Mountain
PP	Paulina Peak
E Oregon Ranges	
SBM	Strawberry Mountains
SM	Steens Mountain
NE Nevada Ranges	
IM	Independence Mountains
JM	Jarbidge Mountains
CM	Copper Mountains
Smaller Salt Lake Basin Ranges	
RRM	Raft River Mountains
SBR	Stansbury Range
OR	Oquirrh Range
Wasatch Range and Uinta Mountains	
WR	Wasatch Range
UM	Uinta Mountains
Utah Plateaus	
WP	Wasatch Plateau
FLM	Fish Lake Mountain
SP	Sevier Plateau
MP	Markagunt Plateau
BM	Boulder Mountain
SW Utah Ranges	
PR	Pavant Range
TM	Tushar Mountains
Utah/Nevada Border Ranges	
DCR	Deep Creek Range
SSR	South Snake Range
NSR	North Snake Range
E-Central Nevada Ranges	
SCR	Schell Creek Range
WPR	White Pine Range
GR	Grant Range

[a]Symbols are shown on Fig. 1; ranges are listed in the order presented in text.

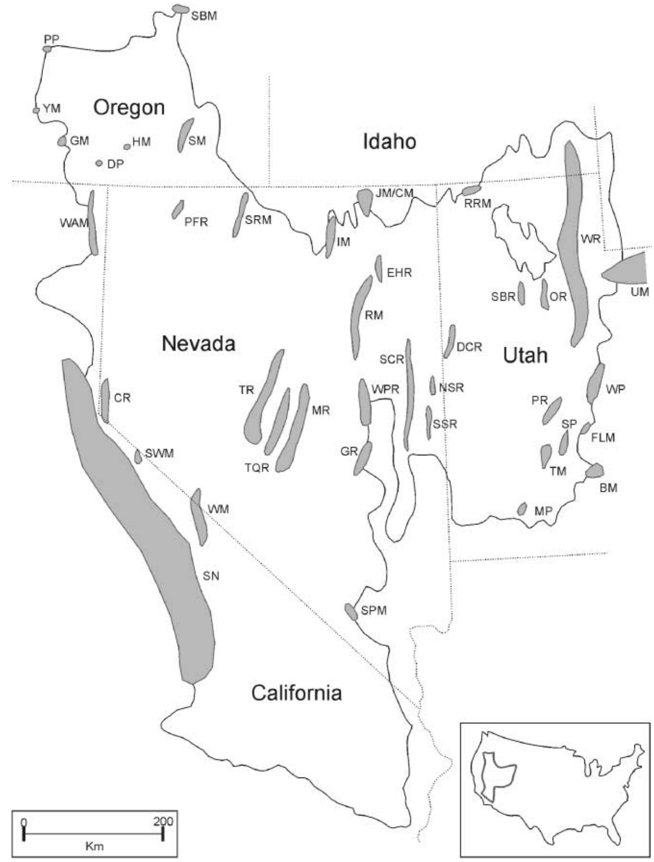

Fig. 1. Index map showing ranges draining wholly or partly into the Great Basin. Symbols defined in Table 1.

A subsequent paper will interpret paleoclimate from these observations.

1.1. Setting

The Great Basin (GB) is a region of internal drainage within the Basin and Range province of the western United States (Fig. 1). It is bounded on the west by the Sierra Nevada and Cascade Ranges, on the south by the part of the Mojave Desert drained by the Colorado River, on the south and east by the Colorado Plateau, and on the north by the Snake River Plain. The GB encompasses broad valleys interspersed with generally north–south-trending, elongate, fault-bounded mountain ranges. The latter rise 300 to 1500 m above intervening valleys. The highest peaks in the interior of the GB, Boundary and Wheeler Peaks, rise to approximately 4000 m elevation, and Mt. Whitney on the western boundary of the Basin rises to 4419 m. Many of the glaciated ranges are of modest elevation and may bear little resemblance to textbook versions of alpine glacial topography (e.g., Fig. 2).

Fig. 2. Northern Toiyabe Range: definitely not a textbook example of a glaciated range, but a km-long glacier left deposits on the opposite (not visible) flank.

The GB constitutes an elevated plateau with a continental temperature regime of cold winters and hot summers, and a large diurnal range in temperature. The region is characteristically dry, as it is located in the rain shadow of the Sierra Nevada and Cascade Range. Basins generally receive less than 20 cm of rainfall per year, while the higher ranges receive more than 50 cm per year. Details of GB climate are discussed by Houghton (1969), Mitchell (1976), and Mifflin and Wheat (1979), among others.

Most of the bedrock found in the higher elevations of the ranges, where the glacial deposits are situated, is either Paleozoic quartzites and/or carbonates, or Tertiary tuffs and/or ash-flow tuffs. Granitic or gneissic intrusions occur in some ranges, for example the Ruby/East Humboldt Mountains, Snake Range and Deep Creek Mountains.

1.2. Previous work

The first overview of GB glacial geology was provided by Blackwelder (1931, 1934) (see also Gillespie et al., 1999), who assigned moraines to the Tioga and Tahoe glaciations he had interpreted in the Sierra Nevada. Later cursory overviews were done by Ives (1946) and Flint (1947); the latter published the first map showing cirque-floor surface elevations across the GB, which map was later modified by Porter et al. (1983) and Zielinski and McCoy (1987). More recent overviews of extant knowledge in a few ranges of the GB are those of Richmond (1986) and Oviatt and McCoy (1992). Original thesis work of regional scope was done by Piegat (1980) and Bevis (1995); the latter is the basis for part of this paper. Dohrenwend (1984) reported on the paleoclimatic significance of nivation forms in the GB. Many papers have been published on Quaternary paleoecology, pluvial lake history, archeology, soil development, and calcite oxygen isotope records of the GB; a few examples are Thompson and Mead (1982), Madsen and O'Connell (1982), Harden et al. (1991), Winograd et al. (1997) and Benson (1999), respectively. A good overview of GB prehistory is provided by Grayson (1993). Papers which deal with glacial history of individual ranges are listed in the appropriate sections below.

1.3. Methodology

Deposits have been mapped through a combination of field study and aerial-photo mapping over the last 10 yr.

Datable organic matter is extremely scarce in deposits of these semi-arid ranges, so very little radiocarbon dating has been possible. Varnish radiocarbon dating has been attempted on deposits in the White Mountains (see appropriate section below), but varnish ages are now considered unreliable (e.g., Harrington et al., 1995; Dorn, 1996). Some moraines in the White Mountains and Sierra Nevada have been dated using cosmogenic isotopes (see below). The quartzites, limestones, and tuffs common in the ranges are not very suitable for some of the relative-dating techniques that have been practiced in the western United States (for example, see discussion in Osborn (1989)), and in such rocks, simple parameters such as lengths of reconstructed glaciers, reconstructed equilibrium-line altitudes (ELA's), and degree of dissection of moraines offer some help in correlation of deposits. Bevis (1995) collected a large amount of data for relative dating in the Strawberry, Steens, Pine Forest, Ruby, Deep Creek, and Tushar Mountains; these data include degree of surface weathering of boulders (surface boulder frequency, % fresh vs. pitted vs. oxidized boulders, pit depths, % split boulders), thickness of weathering rinds on subsurface cobbles, and soil development as measured by particle-size distributions and Harden's (1982) profile development index (PDI).

Minimum ages of cirque moraines in certain ranges were determined by identification of tephras found to overlie the moraines. Glass separates from tephras were analyzed on the automated ARL-SEMQ microprobe at the University of Calgary; details are listed in Osborn (1989).

2. Glacial deposits

Our survey of the GB begins in the interior, in the Ruby and East Humboldt Ranges, because of a long-standing, well-established subdivision of deposits there, and then moves generally clockwise around the GB. Maps of selected glaciated drainages use standard symbols, with hachured lines representing cirque headwalls and dashed lines representing moraine crests; AL = Angel Lake; LAM = Lamoille; PAL = pre-Angel Lake (may or may not be equivalent to LAM). Contours are shown in feet from the original 1:24,000 base maps, except for Fig. 16, which is based on the metric 1:100,000 map for reasons of scale.

2.1. Ruby Mountains/East Humboldt Range

The nearly continuous Ruby/East Humboldt chain, lithologically a combination of quartzite, marble, granodiorite, and granodioritic gneiss, rises to an elevation of 3472 m at Ruby Dome and has the most classically alpine appearance of any range between the Sierra Nevada and Wasatch Ranges. Sharp (1938) elaborated on Blackwelder's (1934) original Tioga/Tahoe subdivision of Ruby deposits; he mapped younger "Angel Lake" and older "Lamoille" moraines on a small-scale (one inch = 8 miles) map. Lamoille deposits are mostly lateral moraines that fade out into alluvium at the mouths of valleys (Fig. 4); terminal moraines are absent in most cases. The moraines are subdued in form and mantled with relatively sparse, mostly quartzite boulders. Richmond (1986) reported a double set of lateral moraines in some valleys and proposed two distinct Lamoille advances; we did not observe such relationships ourselves. Angel Lake moraines are steep-fronted, hummocky, relatively sharp-crested, and bouldery (Fig. 3); end moraines are breached but otherwise well preserved. These end moraines typically are situated a few km upstream of the lowest preserved remnants of Lamoille moraines. Wayne (1984), who studied soil development and relative weathering phenomena on some of the moraines containing granodioritic gneiss boulders, concluded that the Angel Lake moraines are Late Wisconsinan in age, while the Lamoille deposits are Illinoian. Bevis (1995) reached the same conclusion, based on relative dating techniques described earlier. Wayne (1984) recovered bog-bottom organic matter in upper Lamoille Canyon indicating deglaciation had occurred prior to ca 13,000 14C yr BP.

We have mapped deposits from Trout Creek on the north end of the East Humboldt Range south to the vicinity of Cass House Peak in the Rubies, at latitude 40°12′ (a few kilometers south of Sharp's (1939) southern limit). The total length of glaciated crest is approximately 110 km. Angel Lake moraines were constructed by cirque, valley, and piedmont glaciers, and are easy to trace away from the type locality. Angel Lake glaciers varied in length from at least 10 km in Lamoille Canyon (where no definite terminal moraine remains) to less than 1 km in lower-elevation cirques. The Lamoille glacier in the type canyon (Lamoille Creek; Fig. 4) was approximately 20 km long, and as such was the longest Pleistocene glacier yet identified between the Sierra Nevada and Wasatch Range. Some Lamoille moraines are cut by normal faults (Sharp, 1939) (see also Howard et al., 1979).

A slightly hummocky mass of sediment at the west base of the East Humboldt Range (Fig. 5) *may* represent a pre-Lamoille glaciation. Sagebrush-covered soil is littered with scattered boulders up to 1.5 m long, of mixed lithology. The boulders are angular and rough and some are shattered in place. This diamict extends northwest from the normal fault at the base of the range, and is not associated with any modern drainage line, which distinguishes it from Lamoille deposits.

Fig. 3. Surface of the type Angel Lake moraine in the East Humboldt Mountains; boulder frequency and degree of weathering is typical.

Some valleys contain cirque moraines situated several kilometers upstream from Angel Lake terminal moraines. These apparently are the "fossil rock glaciers" referred to by Wayne (1983). Some of these features may indeed be collapsed rock glaciers, but others, such as the one at the head of Thomas Canyon, are distinct moraine ridges. Wayne (1983, p. 1380) implied that some of these features were created during the Angel Lake glaciation, and that some were active once or twice during Neoglaciation, but no evidence is given. We regard them as post-Angel Lake, considering their upvalley positions, but pre-Neoglacial. Tephra recovered from small basins behind some of these moraines, including that shown in Wayne's Fig. 2 and the Thomas Canyon moraine, is of late Holocene Mono Craters, California, affinity, and most likely is the 1200 yr-old tephra noted by Osborn (1989) in the Toiyabe Range. The moraines still could be early Neoglacial in age, but weathering of granitic boulders in them (3-cm deep scallops in fracture surfaces, 4 cm of relief between liesengangen and adjacent host rock) suggests they are pre-Neoglacial in age.

2.2. Central Nevada

The Toiyabe, Toquima, and Monitor Ranges are long, narrow, parallel ranges, each of which rises to over 3300 m elevation. They are composed of a variety of Paleozoic sedimentary rocks capped in places by Tertiary ash-flow tuffs and associated lavas (Stewart and McKee, 1977; Kleinhampl and Ziony, 1985). The highest parts of these ranges are low-relief plateaus scalloped by cirque headwalls; the plateaus have been interpreted

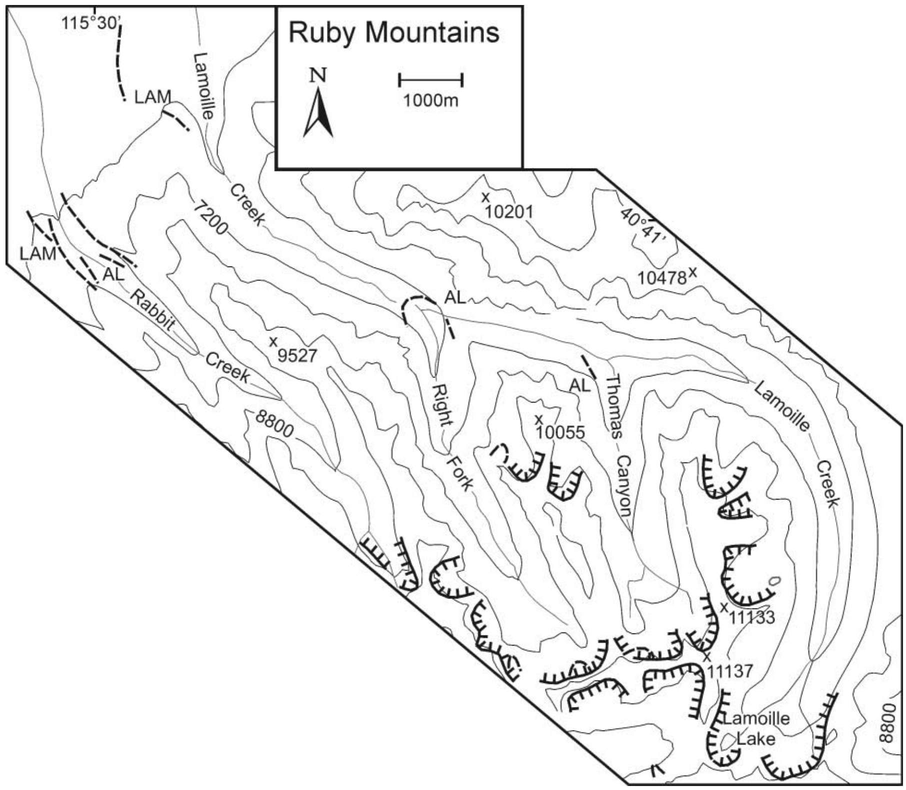

Fig. 4. Moraine positions along Lamoille and Rabbit Creeks in the Ruby Mountains. Symbols and abbreviations for this and all other regional maps in this paper are defined in the text. Source base maps: Lamoille, Lee (Nevada), 1 : 62,500 scale.

(Meinzer, 1917; Ferguson, 1924) to be remnants of an original Tertiary erosion surface that was uplifted and broken by Pleistocene block faulting.

Brief mentions and/or reconnaisance maps of Quaternary moraines in the Toiyabe Range were made by Stewart and McKee (1977), Piegat (1980), and Kleinhampl and Ziony (1985). More recently, Osborn (1989) described three groups of deposits, listed by increasing age: rock glaciers and small cirque moraines situated a few hundred meters or less from cirque headwalls, thick, hummocky, generally well-preserved terminal moraines deposited by valley glaciers a few kilometers long, and uncommon remnants of lateral moraines extending up to one kilometer beyond the above-mentioned terminal moraines. The intermediate and older deposits are very similar to the Angel Lake and Lamoille deposits, respectively, of the Ruby Mountains 180 km to the northeast, and those correlations were made by Osborn (1989). Tuffaceous sediments overlying the younger deposits contain tephra of Mono Craters (California) origin, providing a minimum age of ca 1200 yr BP for those deposits; the Toiyabe Range (and by inference, the other two ranges, which are slightly lower in elevation) did not harbor glacier ice during the Little Ice Age. Osborn (1989) considers the younger deposits to be pre-Altithermal or early Neoglacial in age.

Reconnaisance mapping of moraines in the Toquima Range by Kleinhampl and Ziony (1985) and Boden (1992) indicates deposits in the valleys of Moores Creek, Bucks Canyon Creek, and the north and south forks of Pine Creek. Piegat (1980) in addition noted moraines in the basins of Anderson Creek and South Summit Fork of Pine Creek. The most complete example is at Moores Creek, where a well-preserved, but breached, lateral/terminal moraine loop extends 3 km from the cirque headwall, and an older lateral moraine remnant extends another few hundred meters farther downvalley (Fig. 6). The former moraine we correlate to Angel Lake deposits. The latter is probably equivalent to Lamoille deposits of the Toiyabe Range, but in keeping with the nomenclature of this paper is referred to by the more general term "Pre-Angel Lake" on Fig. 6 since no formal correlation has previously been made. Inferred Angel Lake terminal moraines in Bucks Canyon have the characteristic thick, hummocky aspect of Angel Lake moraines in the Ruby Mountains. Near the head of Moores Creek is a 200-m-long rock glacier (Fig. 7), first noted by Piegat (1980) and regarded by him to probably still be active. Although the deposit does have a sharp top/front angle and a steep front, many of the boulders on both top and front are as heavily weathered as boulders in the Angel Lake moraine, and plants are growing on the front. This rock

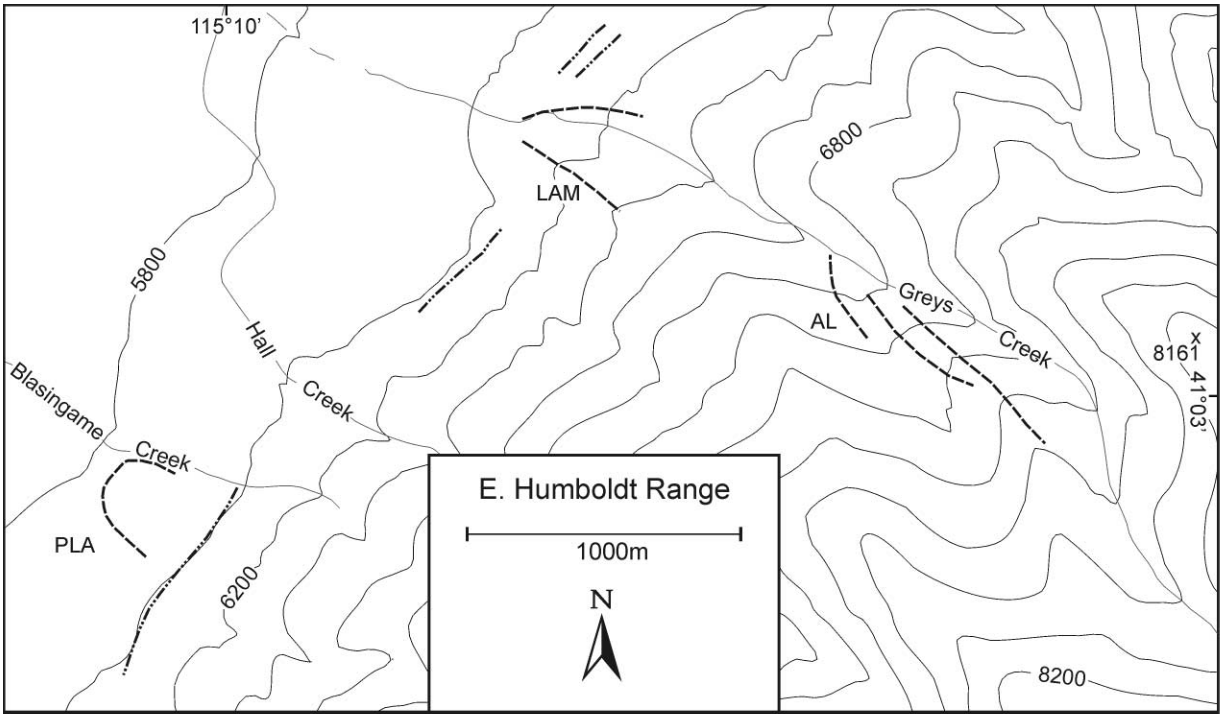

Fig. 5. Moraine positions in the vicinity of Greys Creek, East Humboldt Mountains. Dash–dot lines represent fault scarps. The moraine at Blasingame Creek is interpreted to be a pre-Lamoille (PLA) deposit. Source base map: Herder Creek (Nevada), 1 : 24,000 scale.

glacier was probably formed prior to Neoglacial time but may have been reactivated more recently. Small rock glaciers or cirque moraines also lie at the heads of some of the other valleys.

In the Monitor Range, an obvious moraine loop impounds Clear Lake at the head of Clear Creek, on the east side of the range. This probable Angel Lake moraine, not visited in the field, was deposited by a one-km-long glacier. Other moraines lie at the heads of the forks of Sawmill Creek, and there are cirques without moraines north of Clear Lake and south of Danville Pass which presumably contained glaciers at one time. There is no evidence of the post-Angel Lake cirque deposits found in the other two ranges.

In all three of these ranges the moraine boulders are of ash-flow tuff, a friable material that renders relative dating difficult (see discussion in Osborn, 1989).

2.3. Southwestern Great Basin

The Sweetwater Mountains and the White Mountains are two glaciated southwestern ranges that drain entirely into the GB. The Spring Mountains located in the same region will also be considered. The southwestern margin of the GB is bounded by the Sierra Nevada which will be considered separately.

The Sweetwater Mountains are a small range just east of the Sierra Nevada rising to 3559 m at Mt. Patterson. According to Halsey (1953) the range consists of Mesozoic metasediments and metavolcanics intruded by intermediate to felsic rocks that are now somewhat metamorphosed; the assemblage is capped in places by Tertiary rhyolites and latites.

The glacial history of the range is difficult to decipher. Halsey (1953) found no moraines that he would regard (using Sierran terminology) as Tioga or Tahoe in age, although he thought that "fresh cirques" on the east side of the crest might have held small Tioga glaciers. However, he claims that at least 16 glaciers, 2–10 km long, flowed from the crest during Sherwin (pre-Tahoe) time. The evidence is "patches of till" along most of the glacier courses. Halsey does not map these or outline his criteria for identification, and the alleged till is not identifiable on air photos (we have not been there).

The most obvious glacial deposits in the range are two tongue-shaped rock glaciers, each approximately 750 m long, located one kilometer NNW and 1.5 km NE, respectively, of Wheeler Peak. Their fronts do not appear to be oversteepened and patches of krumholtz are developing on the side of one front, so the rock glaciers are not presently active. However, their almost complete lack of vegetation cover, despite being slightly below treeline, suggests they were active in Neoglacial time. No valley-glacier moraines were observed, but small cirque moraines occur 1.7 km NNW of Mt. Patterson and 1 km ESE of Wheeler Peak. We remain uncertain how these

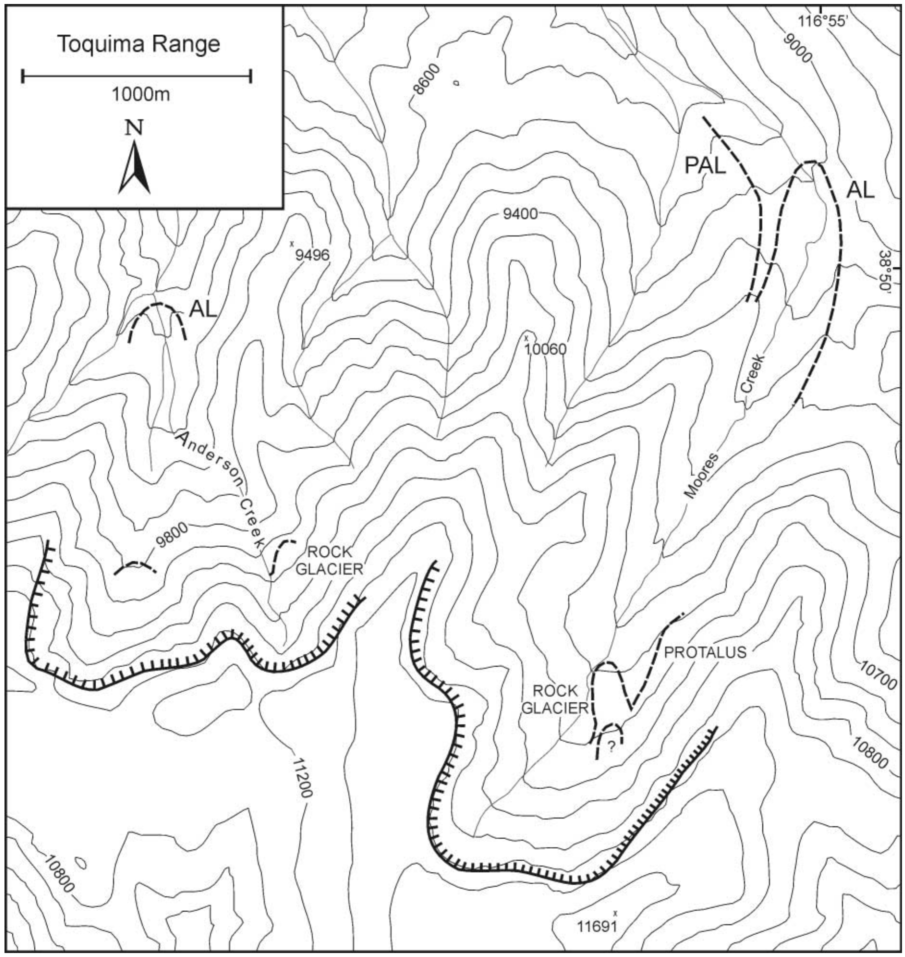

Fig. 6. Moraine positions along Moores and Anderson Creeks in the Toquima Range. Source base map: Mount Jefferson (Nevada), 1 : 24,000 scale.

Fig. 7. Rock glacier at the head of Moores Creek in the Toquima Range, looking downstream from midway along the top surface.

deposits might correlate to those in other ranges. The most unusual deposit, at the SW base of South Sister, is a 2-km-long hummocky, vegetated, tongue-shaped deposit, which bifurcates into two streams going upstream and is laterally bounded in part by leveé-like ridges. The irregular hummocks on the surface do not resemble the ridges and furrows characteristic of rock glacier relief, and the heads of the valleys containing the two streams are not cirques. The feature is most likely a debris flow deposit, but this hypothesis requires the unusual condition that simultaneous failures occurred at two adjacent valley heads.

The White Mountains of eastern California and adjacent Nevada constitute the highest range (rising to 4343 m) that drains entirely into the GB, and consequently supported several relatively long valley glaciers on its eastern flank, despite being in the rain shadow of the Sierra Nevada. The range is composed of plutonic and metamorphic rocks locally covered by basalt flows; glaciated valleys are situated mainly in granite and some cut through metavolcanics as well (McKee et al., 1982). A few valleys on the east side appear to contain more complete moraine records than is usual in GB ranges. Glacial geomorphology was briefly described by LaMarche (1965); decades later D. Elliot-Fisk and colleagues categorized moraines into age groups based on relative-dating methods and rock-varnish radiocarbon

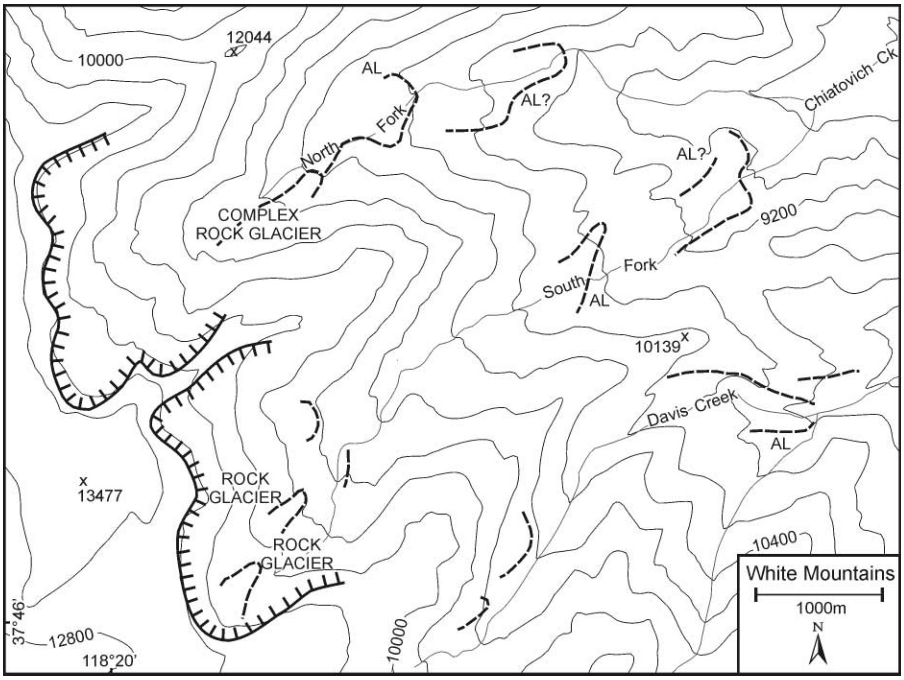

Fig. 8. Moraine positions along Chiatovich and Davis Creeks on the east flank of the White Mountains. Source base map: Boundary Peak (Nevada/California), 1 : 24,000 scale.

dating (e.g., Elliot-Fisk, 1987). Varnish dating has since been criticized as unreliable (e.g., Reneau et al., 1991) and was conceded to be so by its main practitioner (Dorn, 1996), leaving Elliot-Fisk's correlations to Sierra Nevada deposits in doubt. Swanson et al. (1993) published a detailed map of glacial deposits in the South Chiatovich Creek basin; differentiation of deposits was based on a "multi-parameter, relative-dating approach and limited radiometric data", the details of which were never published. Reheis (1994) criticized some of that mapping, suggesting that much of the older ("Indian" and "Dyer") glacial deposits of Swanson et al. (1993) is actually alluvium and colluvium. More recently, Zreda and Phillips (1995) and Phillips et al. (1996) have applied ^{36}Cl surface exposure dating to some of the White Mountain moraines.

The Perry Aiken moraines, described by Elliot-Fisk (1987) as "large massive lateral, medial, and end moraines with broad, flat or hummocky crests", having "great heights" and a "relatively high degree of preservation", were interpreted by her to be correlative with the Tahoe deposits of the Sierra Nevada. But this interpretation is refuted by the ^{36}Cl work (see below), and furthermore the above description (with which we agree, based on air photo studies) matches the description of Angel Lake moraines in the Ruby Mountains and several other GB ranges. The general, though not universal, morphologic consistency of Angel Lake moraines across the GB is striking, and would suggest that Perry Aiken moraines are of Angel Lake/Tioga age even without the surface exposure dating.

The situation is complicated by the fact that some drainages, most notably the North and South Forks of Chiatovich Creek, contain *two* large lobate moraines with steep fronts (designated "AL" and "AL?" on Fig. 8). The more easterly of these along South Fork Chiatovich Creek ("AL?" in Fig. 8) is referred to as "Perry Aiken 1" in the map of Swanson et al. (1993). The more westerly lobate moraine falls within the *upstream* portion of "Perry Aiken 2" on the latter map; i.e., it was not regarded as a terminal moraine by those authors. Phillips et al. (1996) indicate that the Perry Aiken 1 moraine of Swanson et al. is of Tioga age ("Tioga 2" in those authors' terminology), according to ^{36}Cl dating. The Perry Aiken 2 deposits of Swanson et al., containing the "AL" (Fig. 8) moraine of the present study, apparently were not sampled by Phillips et al., but deposits just upstream, which are continuous with and probably the same age as the "AL" moraine of Fig. 8, were dated and labelled "Tioga 3" by those authors. Hence the two massive, lobate moraines we observe in the White Mountains are both of Tioga (Angel Lake) age. We see no definitive terminal or lateral moraines at the downstream ends of the deposits mapped as Early Middle Creek and Late Middle Creek by Swanson et al. (1993), and likewise mapped as Tioga 3 and Tioga 4 by Phillips et al. (1996).

The double set of Tioga (Angel Lake) moraines in the White Mountains does not occur in the GB ranges to the north and east. Multiple sets of Tioga moraines do occur in the Sierra Nevada however (e.g., Phillips et al., 1996), so there is a distinction between Tioga/Angel Lake deposits along the southwestern edge of the GB, and those elsewhere in the GB.

The status of pre-Perry Aiken deposits is uncertain, in part because of the observations of Reheis (1994). The major "Indian" deposit on the detailed map of Swanson et al. (1993) is a ridge that on morphological grounds appears to be a bedrock ridge rather than a lateral moraine. Zreda and Phillips (1995) assigned cosmogenic ages of 150 and >150 ka BP to "Indian" and "Dyer" deposits, respectively, in the Chiatovich Creek basin, but did not provide a map to indicate the sample sites.

Rock glaciers and cirque moraines assigned by Elliot-Fisk (1987) to the Chiatovich Cirque Glaciation and dated by Zreda and Phillips (1995) at 11 ka BP occur at the heads of several east-flank valleys. In one case, at 3530 m feet elevation in the north branch of the North Fork of Perry Aiken Creek, a small rock glacier is superimposed over a small moraine loop, suggesting two episodes of activity.

The Spring Mountains of southern Nevada reach a height of 3634 m at Mt. Charleston, but the range is quite far south. The range was included by Flint (1947) in a table of Great Basin ranges that had been glaciated, based on an unpublished manuscript by Chester Longwell. The location of Longwell's manuscript, if it still exists, is not known to us. Piegat's (1980) interpretation was that the range probably has *not* been glaciated. There are steep-walled erosional ampitheaters heading in the summit ridge of Mt. Charleston, but nothing that is necessarily a cirque, nor are there obvious moraines. However, van Hoesen et al. (2000) in a preliminary assessment have interpreted a diamict with striated clasts at the mouth of Big Falls Canyon (informal name) to be a till or outwash deposit, and the ridge containing it to be a moraine, of suggested early middle Pleistocene age. Presence of old deposits combined with a lack of late Wisconsinan deposits would be problematic. Further work will be required to establish the glacial (or non-glacial) origin of the deposit.

2.4. Sierra Nevada

We have no new contributions to make to the voluminous literature on glaciation of the Sierra Nevada and its satellite crest east of Lake Tahoe, the Carson Range, but because the Sierran east flank drains into the GB and its stratigraphic framework has been the basis of many a correlation (including Blackwelder's GB correlations), we briefly outline the current status of Sierran terminology. Fairly recent reviews may be found in Porter (1983), Fullerton (1986), and Gillespie and Molnar (1995). Blackwelder (1931) distinguished 4 ages of glacial deposits and applied the names "Tioga" and "Tahoe" to the end and lateral moraines constituting the youngest and second-youngest of the groups. He later (1934) would apply these names to two ages of moraines he observed in the interior of the GB. Tioga moraines in the Sierra, generally well-preserved but often breached by streams, have been determined to be of Late Wisconsinan or oxygen-isotope Stage (OIS) 2 age on the basis of radiocarbon and surface-exposure dates (e.g., Fullerton, 1986; Zreda and Phillips, 1995). Moraines assigned by various workers to the Tahoe glaciation, on the basis of downvalley position and greater weathering and denudation, relative to Tioga moraines, have been shown to include deposits of both Illinoian (OIS 6) and Wisconsinan age (Zreda and Phillips, 1995; Gillespie et al., 1999). The meaning of "Tahoe" and the age relationships of Tahoe deposits to "Tenaya", "Mono Basin", and other named Late Pleistocene deposits in the Sierra remains mired in uncertainty.

As for younger moraines, Little Ice Age (LIA) are common in the Sierra, and the terms "Recess Peak" and "Hilgard" have been applied to small moraines downstream of LIA moraines but well upstream of Tioga moraines. Regarded for a time as Neoglacial in age, Recess Peak moraines have been shown to pre-date ca. 11,000 yr BP (Clark and Gillespie, 1997). "Hilgard" moraines in Little McGee Creek were dated by surface exposure to 7–8 ka BP (Zreda and Phillips, 1995), but such results seem questionable because climatic conditions during the first half of Holocene time were not conducive to glacier advance (e.g., Davis and Osborn, 1987; Clark and Gillespie, 1997). Recalibrations of isotope production rates since 1995 have the effect of increasing the Hilgard numbers (D. Clark, personal communication, 2000). Clark and Clark (1995) maintain that Hilgard moraines formed during Tioga recession, by 14 ka yr BP, and hence that the concept of "Hilgard glaciation" should be abandoned.

2.5. Northeastern California/Northwestern Nevada Ranges

The Pine Forest Range is a modest highland with a few closely spaced, moderately high summits, the highest of which is Duffer Peak at elevation 2865 m. Several Pleistocene glaciers clustered around this peak. Bedrock in the glaciated area is granodiorite (Smith, 1973). Smith, on his general geologic map, shows "morainal deposits" in the drainages of Blue Lake/Onion Valley Reservoir, Leonard Creek, Alder Creek, the fork of Big Creek east of Blue Lake, and the fork of Big Creek that heads northeast of Blue Lake. Rennie (1987) reproduced Smith's moraine mapping and selected the Blue Lake and Leonard Creek drainages for detailed study of weathering and soils parameters. Rennie concluded that the large moraine loop impounding Blue Lake (Figs. 9 and 10) is a product of the Angel Lake glaciation, and that indistinct moraines south and east of Onion Valley Reservoir (Fig. 9) are Lamoille in age. A moraine impounding Leonard Creek Lake and another 0.8 km downstream of the lake are designated Angel Lake. Independent

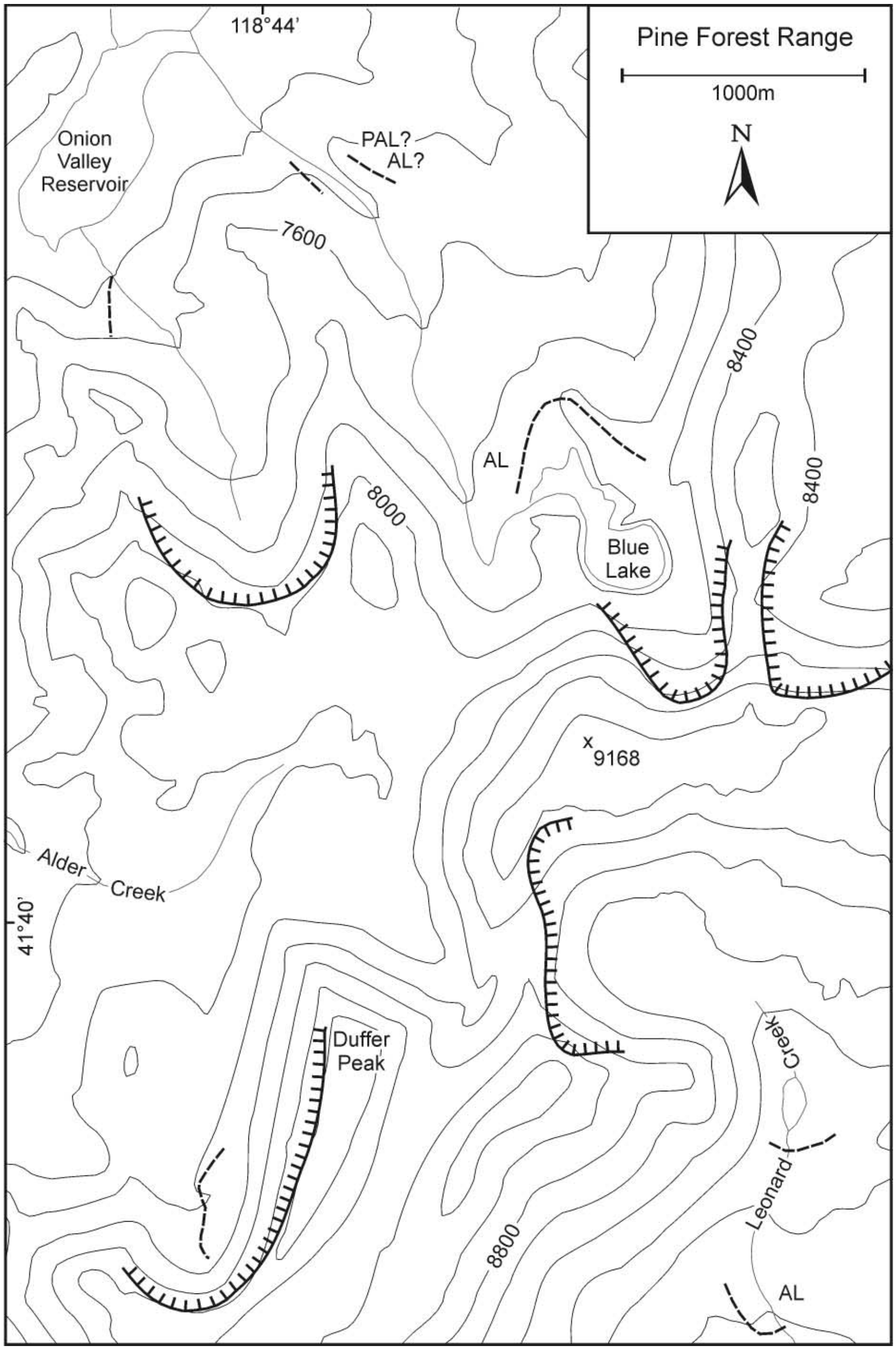

Fig. 9. Moraine positions north and east of Duffer Peak in the Pine Forest Range. The moraine remnants east of Onion Valley Reservoir were interpreted to be of pre-Angel Lake age in the study of Rennie (1987) but of Angel Lake age in the study of Bevis (1995). Source base map: Duffer Peak (Nevada), 1 : 24,000 scale.

relative-dating studies (Bevis, 1995) are in agreement with Rennie's conclusions in the Leonard Creek drainage, but suggest that subdued moraine remnants 2 km downstream of the Blue Lake moraine (east of Onion Valley Reservoir) are no older than that moraine, but are younger than moraine hummocks around Onion Valley Reservoir. Subdued, well-weathered moraines or till sheets similar to the ones around the reservoir also occur in other valleys, beyond inferred Angel Lake moraines. Bevis (1995) found distinct soil PDI differences between the younger and older deposits, although other weathering criteria showed less distinction.

Small cirque moraines on the order of 100 m out from headwalls occur at the head of the Blue Lake cirque and the head of the cirque 700 m southwest of Duffer Peak. The latter moraine is overlain by a primary tephra layer

Fig. 10. The Blue Lake moraine (moraine ridge extends back from foreground to middle-right, then across to left edge of frame) in the Pine Forest Range, interpreted to be an Angel Lake terminal moraine by Rennie (1987).

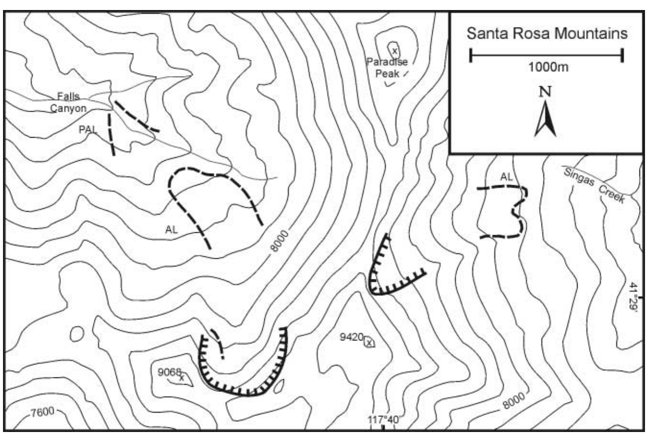

Fig. 11. Moraine positions SW and SE of Paradise Peak in the Santa Rosa Mountains. Source base map: Five Fingers (Nevada), 1 : 24,000 scale.

identified as Mazama, indicating a pre-Altithermal age for the cirque moraines.

The Santa Rosa Mountains rise to 2967 m in northern Nevada and are composed of Mesozoic metasediments overlain by Tertiary rhyolitic and andesitic flows and tuffs, and intruded by small granitic plutons (Stewart, 1980; Vikre, 1985). We identify six glaciated valleys, heading on the north flank of Granite Peak, the north and east flanks of Santa Rosa Peak, the north flank of Paradise Peak, and against unnamed headwalls 1.5 km south and 2.2 km SSW (head of Falls Canyon) of Paradise Peak (Fig. 11), respectively. In these valleys are thick morainal lobes characteristic of Angel Lake moraines, extending one to 2 km down from cirque headwalls. In the Falls Canyon basin, paired lateral moraine remnants characteristic of Lamoille deposits extend farther downvalley. At the head of that basin (underlain by granitic rock) are two small cirque moraines, one partly superimposed over the other; boulder weathering on both of them is similar and not much less than on the inferred Angel Lake moraine.

The Warner Mountains in northeastern California constitute a north–south crest at approximately 2600 m elevation, with individual peaks rising as high as 3016 m (Eagle Peak). The crest is underlain by a thick sequence of flows and tuffs of rhyolitic to basaltic composition according to Duffield and Weldin (1976) and Hulbe (1980). These authors only briefly mention the effects of glaciation. Glacial deposits in a few drainages were mapped by Clark (1995) in conjunction with his study of the Sierra Nevada.

Clark (1995) notes that the largest glaciers in the range (maximum 7 km long) flowed from the large collection area at the head of Pine Creek. The easterly of the two Pine Creek moraines shown on Fig. 12 is a bulky, lobate moraine similar to Angel Lake moraines elsewhere in the GB, but Clark (1995; personal communication, 2000) believes that the downstream (westerly) moraine probably marks the Tioga maximum, based on weathering criteria and generally good preservation of lateral and terminal moraines. Clark (1995) suspects that some glaciers on the east side of the crest, between Horse Mountain and Squaw Peak, flowed to elevations at least as low as 2050 m, although morainal evidence is very scarce, possibly due to the steepness of that side of the range.

We have mapped four well-preserved moraines east of the crest that are farther than a few hundred meters from cirque headwalls: a loop dropping down to 2135 m along North Fork Emerson Creek; the obvious moraine impounding Patterson Lake (also described by Clark (1995)), a small loop immediately southeast of South Emerson Lake, and a hummocky mass filling the head of west-draining Slide Creek. Compositional mixes in till are different at the different sites. The South Emerson and Patterson Lake moraines extend roughly 500 m out from cirque headwalls and descend to 2600–2750 m elevation, and likely represent a latest Pleistocene event, if Clark's (1995) Tioga limits are correct. The North Fork Emerson moraine extends 1.6 km downvalley from a headwall, to 2130 m, and may represent an older (i.e., Angel Lake/Tioga) event, although it is no less well preserved than the others. No particular downstream edge could be determined for the Slide Creek deposit. Small cirque moraines less than 100 m from headwalls are fairly common; a deposit in the Patterson Lake cirque is intermediate between a rock glacier and a moraine (Fig. 13). There is no apparent difference in degree of boulder weathering between the Patterson cirque rock glacier and the Patterson Lake moraine, nor between a small cirque moraine above North Emerson Lake and the North Fork Emerson Creek moraine. There are great differences in boulder frequency, however, as fines are scarce in the small cirque deposits. Clark (1995) surmised

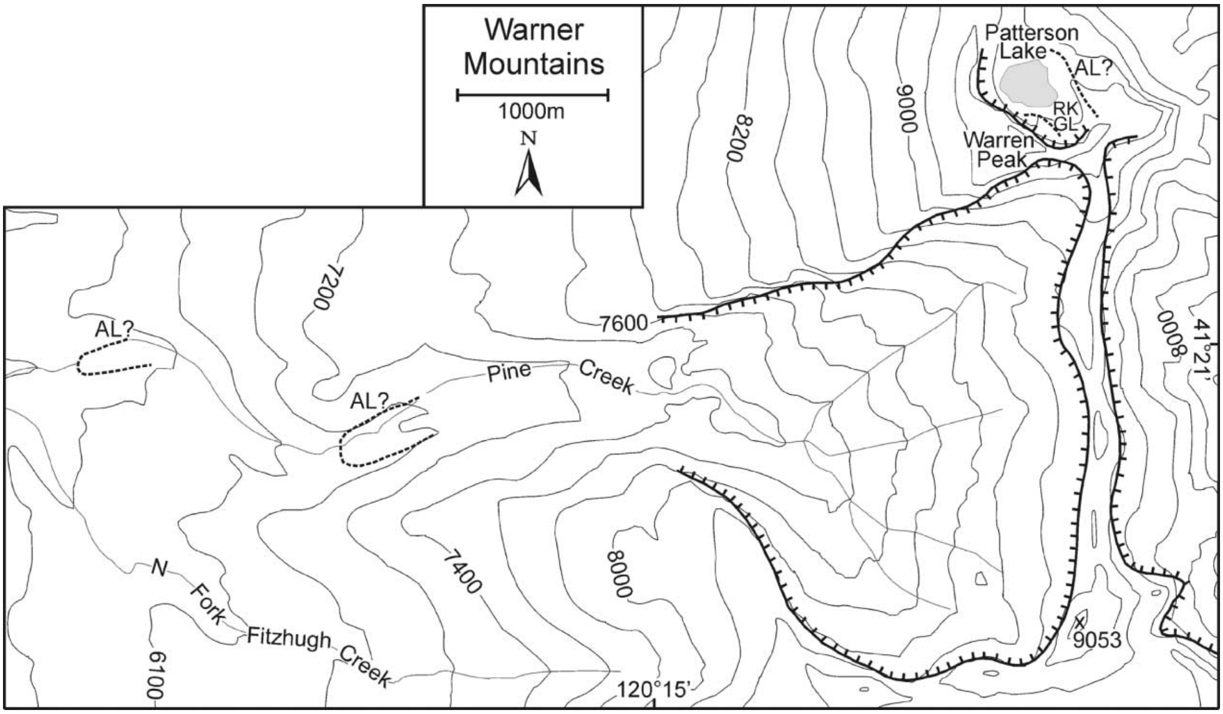

Fig. 12. Moraine positions in the vicinity of Pine Creek in the Warner Mountains. Source base maps: Eagle Peak, Soup Creek, Warren Peak (California), 1 : 24,000 scale.

Fig. 13. Moraine or rock glacier at the head of the Patterson Lake cirque, as seen from the moraine of probable Angel Lake age impounding Patterson Lake.

that the Patterson rock glacier is very young, perhaps LIA in age, because the rate of rockfall from the headwall is so great that the bare bedrock presently exposed in the depression separating rock glacier from wall (Fig. 13) must indicate a young age for the deposit.

2.6. South-Central Oregon Ranges

Drake Peak, Gearhart Mountain, Yamsay Mountain, and Paulina Peak (Newberry Volcano) are all isolated massifs in the basaltic tablelands of south-central Oregon. The former three mountains lie entirely within the GB, while the latter drains partly into the Columbia River system. The elevations of these peaks are 2563, 2632, 2513, and 2434 m, respectively. Hart Mountain, 2443 m, *may* have been glaciated. Glaciation of Gearhart and Yamsay Mountains was briefly mentioned by Crandell (1965).

Reconnaisance mapping of the north flanks of Drake Peak, a fault-block range indicate that cirque glaciers and/or small valley glaciers occupied the headwaters of Twelvemile Creek, Long John Creek, and South Fork Crooked Creek. Based on differences in morphology, glacial deposits in the latter drainage are interpreted to represent two episodes of glacial activity.

At nearby Hart Mountain, the uppermost portions of the North and South Forks of DeGarmo Creek feature cirque-like headwalls and lobate, hummocky deposits within 500 m downvalley. However, these features could be the product of landsliding, a phenomenon not uncommon to the steep scarps of the fault-block mountains in this region. Bentley (1974) was similarly unable to decide, noting "features" with a "scoured appearance", but a "complete lack of depositional material" (p. 221).

Gearhart Mountain, a vent and shield volcano complex, and adjacent Dead Horse Rim were fairly extensively glaciated. The deep cirques and U-shaped valleys of Gearhart and Dairy Creeks contain the most complete record of glaciation. Well-preserved, sharp-crested moraine loops 4–6.4 km downvalley from headwalls appear to be Angel Lake correlatives. More subdued, highly eroded, and discontinuous segments of moraine ridges extending 7–9.5 km from headwalls were deposited by an older glaciation. Small, bouldery cirque moraines occur in some basins.

Yamsay Mountain and Newberry Crater each are composed of basalt, andesite, and rhyolite flows and ash-flow tuffs. Yamsay Mountain displays a well developed cirque complex on its northern flank, drained by Jackson Creek. Small, sharp-crested terminal moraines occur 1.5–2 km downvalley from cirque headwalls, at elevations of approximately 2070 m. These are regarded to be Angel Lake equivalents. No older deposits are apparent. Bouldery material in the uppermost portions of cirque basins may be protalus ramparts.

Paulina Peak, the high point on the caldera rim at Newberry Volcano, marks the northwestern corner of the GB. The volcanic flows and tuffs are described by MacLeod et al. (1995). No glacial deposits are evident well away from the base of the north-facing caldera cliff, but a well preserved ridge (part of the Qls (landslide deposits unit) of MacLeod et al. (1995)) lines the base of the cliff for part of the distance between Paulina Peak and the Big Obsidian Flow. Some of this ridge is certainly moraine, 3–8 m high, separated from the headwall by 40 m (and hence not landslide deposits), and composed of a variety of volcanic materials, as is the cliff above. But other parts, up to 30 m high, line the very base of the talus at the cliff base, and have the appearance of giant protalus ridges. Indeed, these segments may be accumulations of debris that slid over ice and snow mantling the lower cliff. Glass fractions of tephra collected from two 0.7 m-deep pits on the moraine crest are similar in composition to glass of the Big Obsidian Flow (Laidley and McKay, 1971); the tephra is probably part of a widespread pumice fall, dated at ca 1700 yr BP, that was associated with that flow (MacLeod et al., 1981). Considering the relatively low estimated elevation of the head of the glacier (2200 m or less), it is likely that the ridge is a product of Angel Lake glaciation. However, the deposit cannot easily be related to more complete sequences elsewhere.

2.7. Eastern Oregon Ranges

Considered here are the Strawberry Mountains on the northern border of the GB, and Steens Mountain, the northernmost range entirely within the GB.

The Strawberry Mountains, part of the Blue Mountains province, rise to 2755 m at Strawberry Mountain. The western half of the range is underlain by peridotite, gabbro, and serpentinite of the Triassic Canyon Mountain Complex (Brown and Thayer, 1966); the eastern half is underlain by the Tertiary Strawberry Volcanics (basalts and andesites) and Clarno Formation (basaltic to rhyolitic flows, breccias, and tuffs) (Walker, 1990; Walker and Robinson, 1990). Glacial deposits were mapped in the northwestern part of the range by Thayer (1956) and in Big Creek by Brown and Thayer (1966). Bentley (1974) described the glacial morphology of all major Strawberry watersheds, as well as those of the nearby Aldrich Mountains, and inferred deposits of at least two Pleistocene glaciations.

Lobate moraines like those found elsewhere in the GB do not occur here; in fact terminal moraines of any kind, downstream of cirques, are rare. But preserved lateral moraines allow estimation of terminal positions. Bevis (1995) acquired relative-dating data at 20 sites in the Graham (Fig. 14), Strawberry, Lake, and Big Creek drainages. Nearly all relative dating parameters from valley-glacier deposits fall into two distinct groups: the younger deposits are consistent with a OIS 2 or Angel Lake age, while the older deposits may date from OIS 4 or 6. Cirque moraine data indicate such moraines are younger than the two sets of valley-glacier deposits, but the data are otherwise inconsistent. However, one of the youngest cirque moraines according to the weathering data (one km SSE of Strawberry Mountain) is overlain by Mazama ash, suggesting that these moraines in general are of pre-Altithermal age.

Steens Mountain is a fault block range bounded on the east by an imposing 1700-m-high escarpment, and rising to 2967 m elevation. The range contains some of the most spectacular glacial geomorphology in the GB, particularly the U-shaped valleys of Kiger Gorge and Little Blitzen, Big Indian (Fig. 15), Little Indian, Wildhorse, and Little Wildhorse Creeks. Bedrock consists of Tertiary volcanic flows, tuffs, and breccias of rhyolitic to basaltic composition (Langer, 1992). Most glaciated valleys are underlain by the Steens Mountain Basalt (Wilkerson, 1958).

Early discussions of the glaciated character of the canyons were those of Russell (1903, 1905) and Smith (1927). Bentley (1970) studied the glacial geomorphology of the range in a masters thesis, revisited the area in a doctoral thesis (1974), and briefly presented his glacial story in a geologic overview paper (Lund and Bentley, 1976). On the basis of distribution of striations and deposits Bentley concluded that a 300 km^2 ice cap topped the range during an early ("Fish Lake") glaciation, and fed ice into west- and east-flank valleys. A younger ("Blitzen") glaciation was more restricted, but still ice flowed beyond the mouths of Little Blitzen and Indian Creek canyons. Bentley (1970) correlated the two glaciations with the Tahoe and Tioga glaciations of the Sierra Nevada, respectively. We regard Bentley's conclusions as generally correct but erroneous in particular drainages. For example, he (1970) regards irregular, slightly hummocky deposits at the mouths of Mosquito, Willow, and Big Alvord Creeks, probably landslide deposits, to be Fish Lake glacial deposits, and his terminal Fish Lake moraine west of the mouth of Little Blitzen Canyon is actually a brushy bench of basaltic ledges.

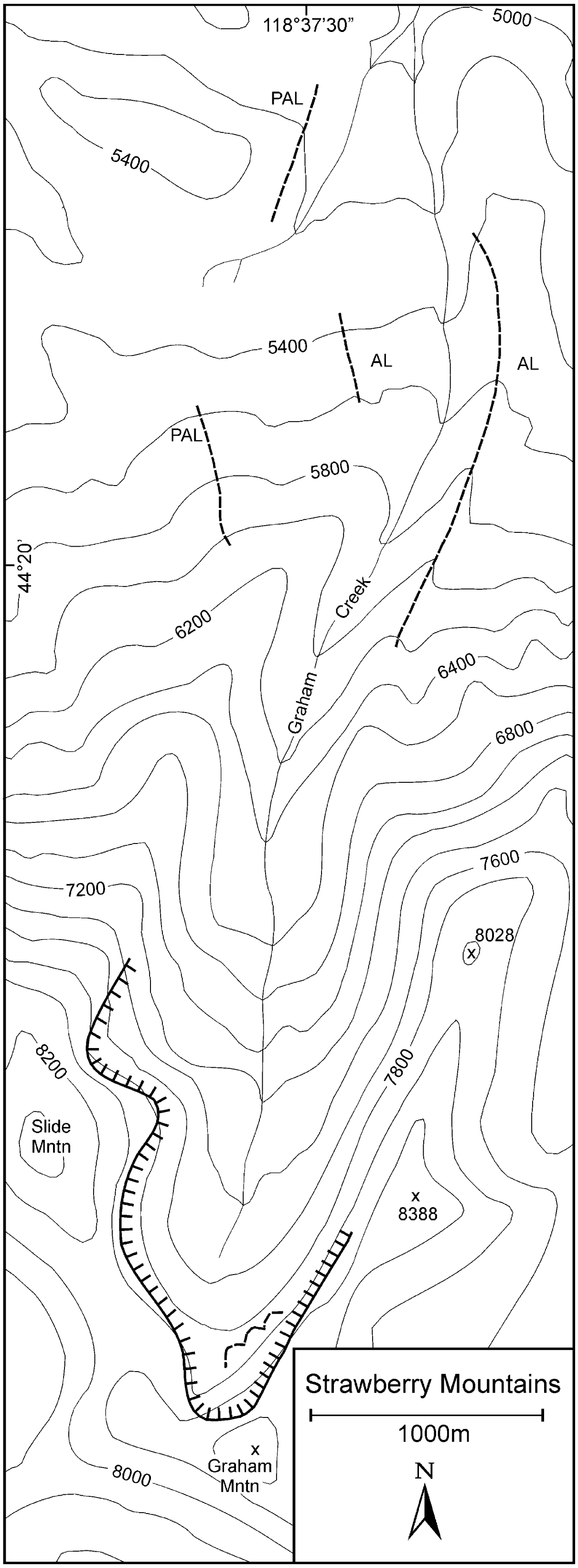

Fig. 14. Moraine positions along Graham Creek in the Strawberry Mountains. Source base maps: Roberts Creek, Strawberry Mountain (Oregon), 1 : 24,000 scale.

Fig. 15. One of the great U-shaped valleys of Steens Mountain, that of Big Indian Creek.

Recent detailed mapping by Bevis (1995) indicates that even during the younger glaciation an ice cap resting on the highest part of the range's west flank fed ice into the radiating valleys. But mapped ice limits of the two glaciations are tenuous in many places due to the paucity of obvious moraine limits or other indicators, even along some of the major drainages. The best surviving terminal moraine complex is just west of the mouth of Little Blitzen Canyon (Fig. 16), and the most obvious distinctions between younger and older deposits can be made in the northeastern part of the range. The only surviving terminal moraine with a distinct lobate character is found along the North Fork of Mosquito Creek.

Bevis (1995) collected relative-dating data at 22 locations at Steens Mountain. Older and younger drift units can be distinguished but weathering and soil PDI parameters do not necessarily suggest that the units are products of different major glaciations. The younger unit, which includes the lobate moraine at Mosquito Creek and the terminal moraine complex west of Little Blitzen Canyon (Fig. 16), probably formed during isotope Stage 2 (Angel Lake) age; the older may be a product of Stage 4 or 6 glaciation.

Cirque moraines, common in the range, were interpreted to be probably of Neoglacial age by Bevis (1995). A more detailed look at the head of South Fork Willow Creek (south half of Section 18) indicates there are two ages of cirque deposits here (Fig. 17). Sheltered by the highest point in the range is what appears to be a permanent (as of 1994) snow/ice bank containing impermeable ice with interlayered talus, and thin transverse crevasses. This was probably a small glacier during the Little Ice Age. Two hundred meters downstream of this ice is the front of a small rock glacier, mostly bare of vegetation, whose boulders are intact and without weathering pits. Three-hundred meters farther down is a well vegetated

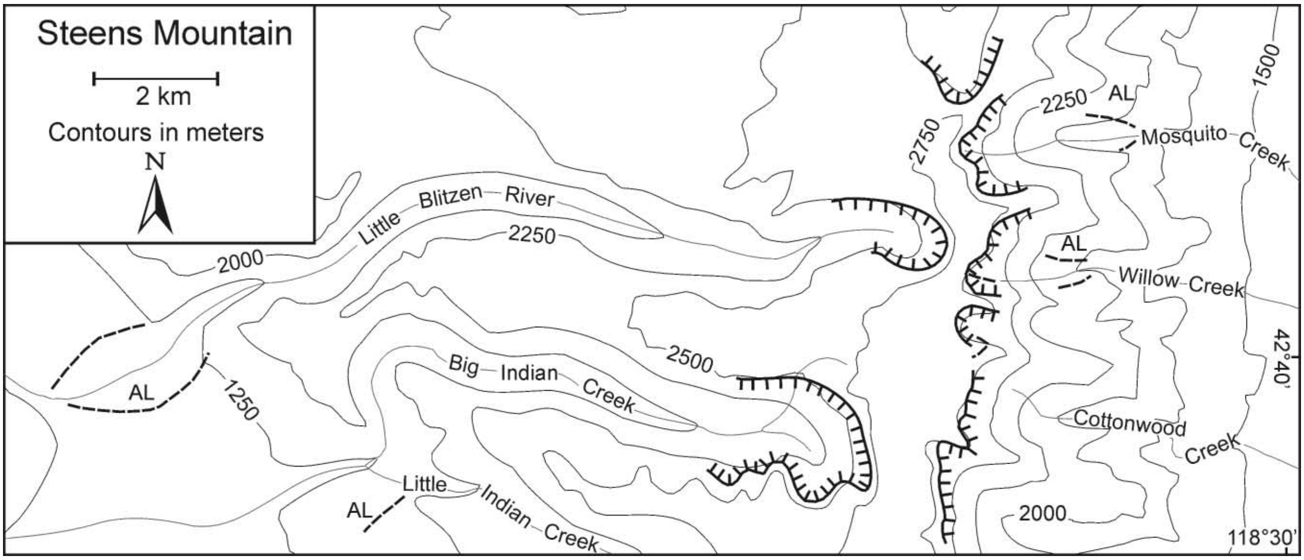

Fig. 16. Moraine positions in a central portion of Steens Mountain. Elevations are in m. Source base map: Steens Mountain (Oregon), 1 : 100,000 scale.

Fig. 17. Two ages of deposits at the head of Willow Creek on the east flank of Steens Mountain. The younger (rock glacier) extends down and to the left of the snowpatch; the older (moraine) is marked by arrows. The small moraine loop in middle foreground is also an "older" deposit.

terminal moraine with disintegrating and pitted boulders. The rock glacier must be Neoglacial, and possibly LIA in age, but grassy patches on the front indicate it has not moved recently. The moraine, and by inference many of the other cirque moraines in the range, is probably pre-Altithermal in age.

2.8. Northeastern Nevada Ranges

The Independence and Jarbidge/Copper Mountains are relatively small ranges whose southern parts drain into the GB and northern flanks drain into the Snake River system.

The Independence Mountains of northeastern Nevada, underlain by Paleozoic quartzite, culminate in a long summit crest capped by McAfee Peak (3182 m). Thirteen valleys heading in this crest, some shown in Fig. 18, were occupied by Pleistocene valley glaciers. Lateral and terminal moraines of the most recent glaciation are obvious and allow reconstruction of Angel Lake glaciers that ranged from 1.5 km in length (heading in the relatively unprotected, ESE-facing Walker Creek cirque) to 5 km in length (heading in the north-facing Chicken Creek cirque). Many of the Angel Lake terminal moraines are thick (e.g., 60 m in the forks of Pratt Creek), hummocky piles with steep fronts (Fig. 19). The moraines on the southeast flank of the crest tend to be unbreached (Fig. 19); moraines in the forks of Mill Creek are breached by streams but still generally well-preserved; the moraine at Chicken Creek has been washed away by lateral shifting of the creek.

Boulder-studded remnants of ridges along Chicken and South Fork Pratt Creeks *may* represent pre-Angel Lake lateral moraines. A better example is at McAfee Creek, where laterals extend over 1 km downstream of the Angel Lake terminal, eventually to fade out on the piedmont at the base of the mountains. This is exactly the relationship that Lamoille moraines have to Angel Lake deposits in the Ruby Mountains, and it is reasonable to equate the McAfee Creek ridges to Lamoille moraines.

Small cirque moraines situated 100–300 m from cirque headwalls are found at the heads of Forman, Chicken, Beadles, and the South and East Forks of Mill Creek.

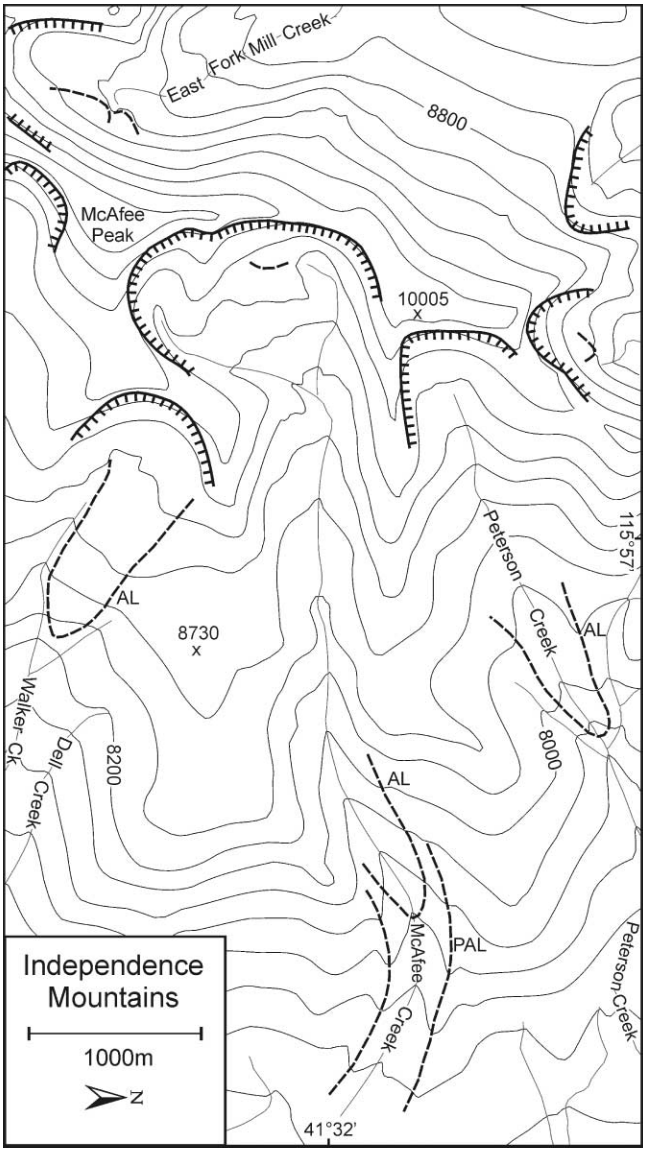

Fig. 18. Moraine positions in a central portion of the Independence Mountains. Source base map: McAfee Peak (Nevada), 1 : 24,000 scale.

Fig. 19. Small Angel Lake moraine (arrow), not associated with any present creek, situated between two forks of Pratt Creek in the Independence Mountains.

These partly vegetated moraines consist mostly of large quartzite blocks whose weathering characteristics are no different than those of boulders on Angel Lake moraines. Tephra identified as Mazama was collected from small sediment basins on the moraines in the valleys of Beadles Creek and the forks of Mill Creek. Near the head of the East Fork of Mill Creek a small bouldery moraine overlain by Mazama is superimposed over an older 6-m high morainal ridge, suggesting two very minor pre-Altithermal advances occurred. There is no evidence of Neoglacial activity.

The Jarbidge Mountains are glacially sculpted highlands cut in basaltic to rhyolitic flows and tuffs and underlying quartzite; their satellite, the Copper Mountains, are underlain by quartzite. The highest peaks of the Jarbidge are aligned along a single ridge that culminates at the Matterhorn (3304 m) (Fig. 20); the highest point in the Copper Mountains is Copper Mountain at 3022 m. Jarbidge glacial geology was briefly described by Coats (1964) as part of a general geologic study; he interpreted three ages of glacial deposits. The oldest consists of patches of diamict on the floor of the Bucks Creek canyon, northwest of the town of Jarbidge, and between Jenny Creek and the Mahoney Ranger Station. The intermediate deposits are in valleys that head in rather subdued cirques, mainly on the west side of the main ridge, while the youngest valley deposits, mainly to the east of the ridge, are in valleys heading in prominent cirques. Coats assigned the intermediate and younger deposits to the Lamoille and Angel Lake glaciations, respectively. We have not examined the oldest deposits, which are described as till-like, but it is not clear how the Buck's Creek deposit, if very old, could have survived stream erosion in the V-shaped canyon. The intermediate and young deposits are distinguished not by characteristics of the till (indeed, Coats notes that there are no weathering distinctions to be made between the various ages of deposits) but by interpreted differences in the freshness or age of glacial geomorphology. Insofar as differences in morphology on the east and west sides may be due to differences in snow accumulation rather than age, and terminal positions are very hard or impossible to determine on both sides of the range, we see no basis for splitting the valley deposits into different ages.

Coats (1964) indicates that terminal moraines of the youngest age (i.e., on the east side of the crest) still retain their original form, but this does not seem to be the case. There are no definite terminal moraines in the east-side valleys except at elevation 2225 m on Fall Creek. There is

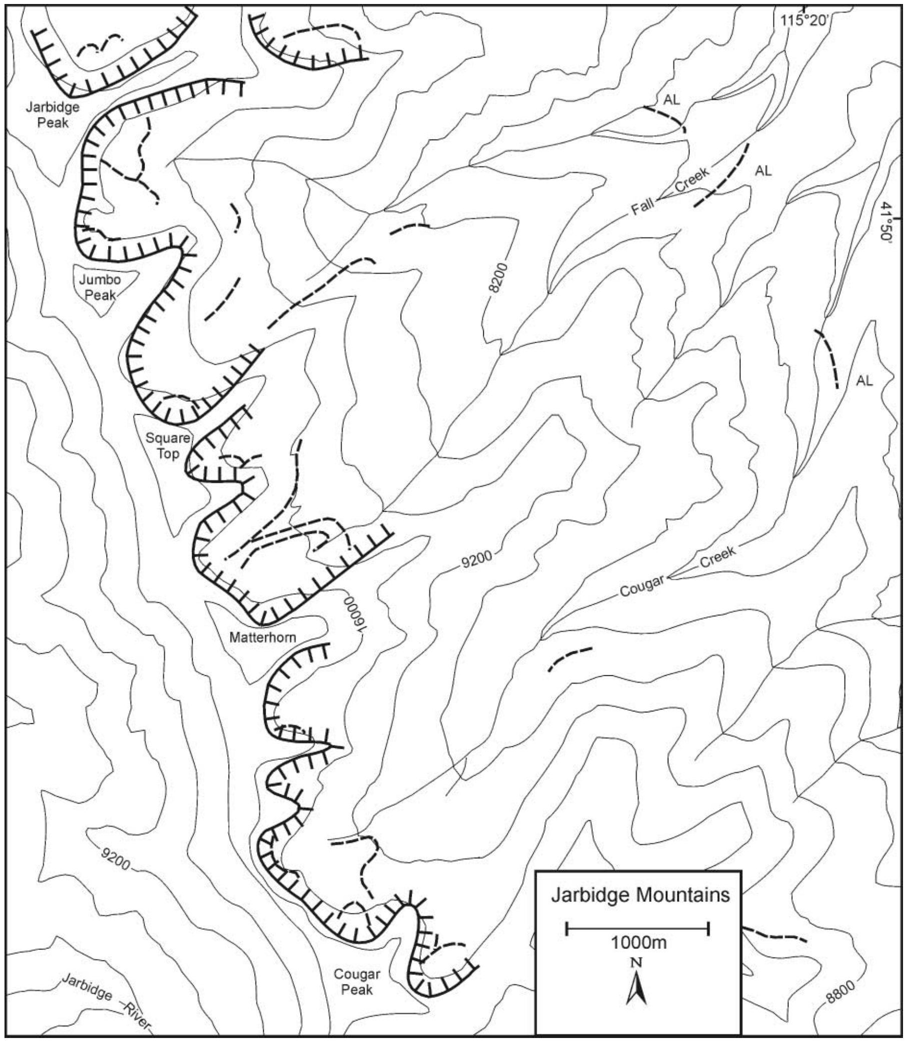

Fig. 20. Moraine positions along part of the east flank of the Jarbidge Mountains. The moraines designated AL were included in Coats' (1964) "youngest" category. Source base maps: Gods Pocket Peak, Jarbidge South (Nevada), 1 : 24,000 scale.

a slightly hummocky bouldery bench at elevation 2225 m on Cougar Creek which may represent a terminal position (Coats maps glacial till downstream of this point, but our own observations could not verify it). If these deposits are Angel Lake in age, the respective late Wisconsinan glaciers were approximately 4 km long.

Moraines in the Copper Mountains are much better preserved, apparently due to lesser stream downcutting. The moraines have the lobate form typical of many Angel Lake moraines, and were deposited by glaciers up to 2 km long.

Cirque moraines and rock glaciers are common in the Jarbidge and Copper Mountains, and in some cases there are two ages of cirque deposits. The best examples of the latter are on the north flank of Cougar Peak, where a small moraine is superimposed over a larger lobate moraine (Fig. 21; also shown on Fig. 20), and on the north flank of the Matterhorn, where an older moraine or rock glacier is partly buried by a tongue-shaped rock glacier emanating from the Matterhorn, and also partly buried by small moraines built out from the north side of the cirque. Boulder weathering (on rhyolite) is consistent between the two groups of deposits, and deposits of both groups are partly barren of vegetation and partly forested. Tephra was not recovered from any of the Jarbidge moraines, but was found overlying a cirque moraine in the Copper Mountains. It consists of an even mixture of Mazama tephra and some unknown tephra with possible Mono Craters affinity. It is likely that both groups of cirque deposits in the Jarbidge are pre-Mazama in age, based on weathering patterns and association with the Copper Mountains moraines. However, a Neoglacial age for the younger deposits cannot be ruled out.

Fig. 21. Two ages of cirque moraines in the cirque on the north flank of Cougar Peak in the Jarbidge Mountains. The corrugated appearance of the older, lobate moraine suggests the deposit may be a deflated rock glacier.

2.9. Smaller Salt Lake Basin Ranges

Close to the modern Great Salt Lake and draining partly into it are the Raft River Mountains and Stansbury and Oquirrh Ranges. Also draining into the Salt Lake Basin, but considered separately, are the Wasatch Range and the west end of the Uinta Mountains.

The Raft River Mountains are a small, flat-topped, east–west-trending range in northwestern Utah, underlain by quartzite and granite. The high point (unmarked on maps) is slightly over 3030 m in elevation. The only known mention of Quaternary geology is a paper reporting Mazama tephra in a bog in Curelom (or Bull Lake) Cirque on the north flank of the range (Mehringer et al., 1971). These authors suggest that probable glacial deposits occur downstream of the cirque, and indeed the local U-shaped valley suggests that might be the case, but we could find no moraines inferred to be Pleistocene in age, in air photos or on the ground. Assuming there was a glacier emanating from the cirque, it was gone by ca 12,200 yr BP, the age of organic matter from a cored bog in the cirque. There are two cirque deposits in the range, a small moraine east and down from Rosevere Point, and a rock glacier in the Bull Lake cirque, whose middle step suggests two ages of activity. Mehringer et al. (1971) regard the broad, irregular ridge damming the swamp downstream of Bull Lake to be a moraine, and it is studded with occasional boulders, but we are uncertain of this interpretation because the ridge does not have typical morainal morphology.

Mazama tephra was recovered from sediments overlying the moraine below Rosevere Point, so that and the similarly positioned Curelom rock glacier appear to be pre-Altithermal in age.

Because glacial activity was restricted to the north flank of the range, all glacial meltwater drained into the Snake River system rather than into the GB.

The Stansbury Range, south of the Great Salt Lake, rises to 3363 m at Deseret Peak. The range is underlain by Paleozoic sedimentary rocks, intruded in a few places by very small monzonite plugs; the glaciated areas of the range are underlain almost entirely by Tintic Quartzite (Rigby, 1958; Sorensen, 1982). Glaciated valleys are described by Rigby (1958), and morainal deposits are included in the "surficial deposits" unit on Sorensen's (1982) map.

Glaciers filled several valleys heading along the high crest between Deseret Peak and Peak 10217 (adjacent to North Willow Lake); these are shown in part in Fig. 22. Three glaciers flowed eastward from a secondary crest southeast of Deseret Peak (west of Box Elder Pass), and a third group of three compound glaciers headed at the Vickory Mountain crest farther south. Many of the valleys contain well-preserved, thick, lobate terminal moraines typical of the Angel Lake glaciation; examples are Big Pole and Little Pole Canyons and all the valleys on the east flank of Vickory Mountain. However, only lateral moraine ridges projecting down toward valley bottoms are left in the valleys heading at North and South Willow Lakes, respectively, and in South Lost Canyon. There is very little moraine preservation at all in Mill Fork Canyon, but a small morainal lobe at 2440 m (8000 ft in Fig. 22) probably marks the downstream Angel Lake limit. Rigby (1958) claimed ice extended to 7100 ft (2165 m) in that drainage, but poorly exposed diamict at that elevation is, judging from air photos, fan alluvium/colluvium. In general, Angel Lake glaciers ranged from 0.8 to 2.5 km in length.

We consider there to be only one reliable example of a moraine remnant farther downstream than an interpreted Angel Lake moraine. In the valley heading at North Willow Lake, the Angel Lake moraine projects to a terminal position at 2290 m, while an older, lower lateral moraine projects to 2165 m.

Valley-head moraines are common. Two closely spaced moraine ridges (or one double-crested moraine) occur 0.5 km northeast of North Willow Lake, immediately northeast of South Willow Lake, and in the cirque below the great northeast face of Deseret Peak, respectively. The quartzite boulders in these moraines tend to be angular and occasionally fractured in place; a few are colored with a reddish-brown surface stain. They appear similarly weathered to the boulders in the Angel Lake moraines.

A few valleys, such as South Lost Creek and Big Creek, contain small, probably recessional, end moraines located approximately half way between headwalls and Angel Lake moraines.

The Oquirrh Range, known mainly for metal ores, rises to 3238 m at Flat Top Mountain. Although plutonic

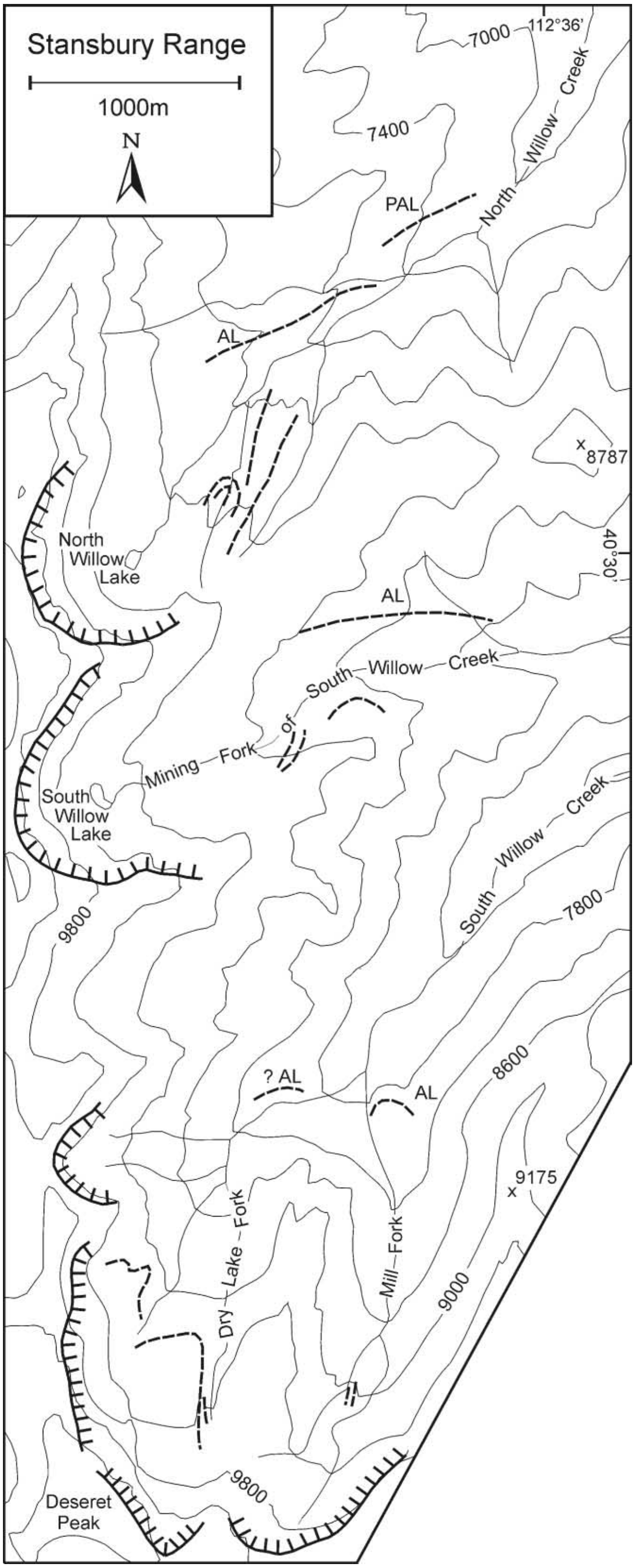

Fig. 22. Moraine positions along the east flank of the main crest of the Stansbury Range. Source base maps: Deseret Peak East, Deseret Peak West, North Willow Canyon, Salt Mountain (Utah), 1 : 24,000 scale.

and volcanic rocks occur, the glaciated portion of the range is underlain by quartzites and limestones of the Oquirrh Group (Tooker and Roberts, 1971). Small glaciers extended east and west from the crest between Peak 10321 (just north of Kelsey Peak) and Flat Top Mountain. The most prominent moraine is a well-preserved 90-m-thick, steep-fronted lobe whose top surface is named The Jumpoff, at the head of Left Fork West Canyon. This moraine was constructed by a 2.3-km-long glacier, and is assigned to the Angel Lake glaciation. Other Angel Lake moraines also exhibit a lobate morphology (e.g., 1 km north of Rocky Peak), while some are more ridge-like (e.g., 1.2 km east of Lowe Peak). Some drainage heads, such as White Pine Flat, are mantled with hummocky till without any distinct downstream limit.

Emanating from the base of The Jumpoff moraine is a 600-m-long lateral moraine remnant, descending to 2135 m elevation, which represents an older glaciation. Lateral remnants descending to 2155 m in Jackson Hollow are probably equivalent.

2.10. Wasatch Range and Uinta Mountains

Although the crest of the Wasatch Range is sometimes regarded to mark the eastern margin of the GB, even the drainage on the east flank of the range eventually flows back westward into the GB. The high point of the range is Mt. Nebo at 3637 m. The range is considered to be part of the Rocky Mountains, thus modern literature on glacial deposits here uses the "Pinedale/Bull Lake" terminology developed in Wyoming. A satellite of the Wasatch Range, the Bear River Range, is situated west of Bear Lake.

Gilbert (1890), Atwood (1909), and Blackwelder (1931) made early observations of the prominent moraines at the mouths of Bells and Little Cottonwood Canyons, and the moraines' relationships to Lake Bonneville sediments. Atwood produced the only published map to this day that shows the extent of Pleistocene glaciation in a large area of the range (he missed a few small areas in the vicinity of Mt. Nebo). He shows that the longest glacier in each of two "glacial epochs" was in Little Cottonwood Canyon (approximately 18 km in late Wisconsinan time). Numerous other commentators on Little Cottonwood/Bells Canyon moraines are listed by Richmond (1986) and Scott (1988). Richmond (1964) made a detailed map of glacial deposits in those two canyons, but some of his stratigraphic conclusions were refuted by Madsen and Currey (1979). The latter authors concluded from radiocarbon and relative dating that the older of the two main canyon-mouth moraines is older than 26,000 yr in age and probably dates from isotope Stage 6, while the younger moraine is younger than 26,000 yr BP but older than 12,300 yr BP and hence Pinedale (Stage 2) in age. Other recent works are those of McCoy (1977), who interpreted ages of deposits in Little Cottonwood Canyon; Gallie (1977), who reconstructed the ELA and mass balance of the Little Cottonwood Canyon Pinedale glacier; and Hart (1978), who studied the glaciation of Big Cottonwood Canyon. The latter is cited by Madsen and Currey (1979) but is not known to University of Utah librarians. Elliot Lips of the University of Utah (personal communication, 2000) is at the time of writing doing another study of the major west-flank deposits to see if ages of moraines can be reconciled with well-constrained ages of high Lake Bonneville stands.

The most prominent, accessible, and well-studied late Wisconsinan moraine in the range is the Bells Canyon moraine adjacent to the mouth of Little Cottonwood Canyon; it is assigned to the Bells Canyon Till, which is younger than ca. 26,000 yr old and considered Pinedale in age by Madsen and Currey (1979). Although part of this moraine is a looping lateral/terminal ridge, the ridge is just a cap on a thick lobe of till deposited on the piedmont; in this sense the moraine is similar to Angel Lake moraines elsewhere in the GB. Madsen and Currey (1979) also mapped pre-12,300 yr BP, mid-valley "Hogum Fork" moraines, also assigned to Pinedale. Some but not all of these mapped moraines are apparent in the field and/or on air photos. Most other ranges in the GB do not appear to have intermediate-ice-extent moraines such as these, although the Stansbury Mountains do.

Small remnants of pre-Pinedale moraines remain at the mouths of Bells and Little Cottonwood Canyons (see geologic maps of Ives (1950) and Scott (1988)). The only numerical age for these is the minimum-limiting age of ca. 26,000 yr BP of Madsen and Curry (1979) noted above, but they are regarded as "Bull Lake" or OIS 6 in age based on relative weathering criteria (McCoy, 1977; Madsen and Currey, 1979). Ives (1950) mapped still older "Graniteville Erratics" at the mouths of Bells and Little Cottonwood Canyons, but these have not been dealt with by later authors and were not observed in the present study.

Cirque deposits are abundant in the range and have been described most notably in Little Cottonwood Canyon by McCoy (1977) and Madsen and Currey (1979), and in the vicinity of Mt. Timpanogos by Anderson and Anderson (1981). The simplest relations are at Timpanogos, where the host bedrock is quartzarenite. The 0.5-km-long, tongue-shaped Timpanogos rock glacier (referred to as the Timp Glacier by Kelsey (1989), apparently on the basis of snow that tends to linger through the summer) is regarded as Neoglacial in age by Anderson and Anderson on the basis of clast weathering rind thicknesses. A steep-fronted upper part of the rock glacier they regard as probably Gannett Peak (LIA) in age although there is no difference in clast weathering. A moraine downstream of and to the east of the toe of the rock glacier, on the edge of the Hidden Lakes cirque, is composed of more-weathered clasts and is thought by the Andersons (1981) to be pre-Altithermal, an age with which we agree. These relationships also occur in Timpanogos Basin, due north of the peak, where a vegetated, lobate sheet-moraine (possibly a sheet of ablation till) with a distinct front extends to 1.5 km out from the cirque headwall. Situated on a bedrock shelf at the base of the headwall is a lobate mass of till designated "undifferentiated rock glacier debris" by the Andersons. Based on its morphology, relationship to the rock shelf, and weathering rinds similar to those on the Timpanogos rock glacier, we feel this deposit is very probably a Neoglacial moraine.

There are at least two and maybe several ages of cirque deposits in Little Cottonwood Canyon and vicinity, but estimating even gross numerical ages is difficult. One bog-bottom minimum age (7515 ± 180 yr BP) is available for the forested Devil's Castle deposit at the head of Little Cottonwood Canyon (Madsen and Currey, 1979). The boulders here unfortunately are of limestone, so weathering of this dated deposit cannot be compared to weathering of the granitic boulders of the prolific cirque moraines and rock glaciers at the heads of Bells Canyon, Hogum Fork, Maybird Gulch, and Red Pine, White Pine, and Gad Valleys. Relative-weathering data collected from these latter areas by McCoy (1977) appear more as continua than as discrete groups, but using cluster analysis McCoy concluded there are two or three ages of pre-Altithermal deposits and two ages of early Neoglacial deposits. Although Richmond (1964) mapped several of the deposits in these tributary drainages as belonging to his "Historic Stade" (LIA), McCoy concluded that only a single rock glacier at the head of the west branch of Hogum Fork is of that vintage. While McCoy's relative-age assessment is probably as good as can be done, the limitations of the method in this particular area are such that we remain unsure of his conclusions. For example, we do not concur that the Hogum Fork rock glacier is necessarily different enough from all the other deposits to be assigned a different age. Using morphology and superposition as guides, there could be as few as three ages of cirque deposits, at least one of which is pre-Altithermal (Devil's Castle equivalents) and at least one of which is Neoglacial. There does not appear to be sufficient data with which to *confidently* state there either was or was not LIA ice in the area.

At the time of writing there is no published mapping from the Bear River Range, the northern satellite of the Wasatch Range. However, both Darrell Kaufman of Northern Arizona University (personal communication, 2000) and Marith Reheis of the US Geological Survey (personal communication, 2000) have observed Pleistocene glacial deposits in the range. Reheis has mapped what she considers to be Pinedale and Bull Lake moraines.

The very western end of the Uinta Mountains drains into the Great Salt Lake via the Weber River and its tributaries. Quaternary deposits in the upper Weber River basin were mapped by Oviatt (1994); he determined that an icefield in the uppermost part of the basin sent distributary glaciers down major valleys. The icefield/valley glacier occupying the main stem of the Weber River was approximately 23 km long. Oviatt regarded all the glacial deposits he mapped to be products of Pinedale Glaciation.

Most of the Uinta Mountains drain into the Colorado River system, and the glacial study that has been done in the rest of the range (most notably that of Atwood (1909), Bradley (1936), Kinney (1955), Osborn (1973), Martin et al. (1985), and J. Munroe (Ph.D. thesis in progress at time of writing at University of Wisconsin — Madison) will not be outlined here.

Fig. 23. Two ages of moraines NE of Widgeon Bay (Fish Lake) on the Fish Lake Hightop. The younger (Angel Lake) moraine is a thick, steep-fronted lobe of till (small arrow in middle of steep front), while the pre-Angel Lake moraine (large arrow) is a continuous low ridge. The responsible ice in both cases emanated from the cirque indenting the skyline ridge just right of skyline center.

2.11. Utah Plateaus

The High Plateaus of Utah are a series of generally flat-topped and cliff-walled uplands, underlain mostly by Cenozoic volcanic and sedimentary rocks, in the central and southwestern parts of the state. They are the only part of the Colorado Plateau within the GB. Dutton (1880), Hunt (1956), Anderson and Rowley (1975), and Rowley et al. (1979) have provided geological and/or geographical reviews. The former two reports briefly mention evidence for Pleistocene glaciation. Glaciated plateaus draining partly or wholly into the GB are the Wasatch, Fish Lake, Sevier, and Markagunt Plateaus, and Boulder Mountain (which is part of the Aquarius Plateau). The slopes ringing these plateaus tend to be underlain by hummocky slump masses and other colluvium, sometimes rendering moraine identification difficult.

The long, narrow, flat-crested Wasatch Plateau rises to 3440 m elevation. Cirques line the eastern rim of the plateau and some north-facing slopes. The uppermost strata (Cretaceous/Tertiary sandstone, conglomerate, shale, and limestone) and the glacial geomorphology and deposits are well described by Spieker and Billings (1940). These authors map one main set of moraines, which they assign to "Wisconsin" time and we correlate to Angel Lake deposits elsewhere. Glaciers were up to 6.5 km long. The largest moraines, between Mill Canyon and Huntington Reservoir, are described by Spieker and Billings (1940) as "sheets of till, 200–300 ft thick, characterized by knob-and-kettle topography, and as a rule by steep, well-defined frontal slopes" (p. 1184). This description tends to fit other Angel Lake moraines in the GB. Cirque moraines are common below the east rim. Spieker and Billings (1940) saw no evidence of pre-late Wisconsinan deposits (nor do we), and speculated that the plateau may have been below the snowline before late Pleistocene time and was subsequently raised by regional uplift.

Fish Lake Mountain is a topographically complex upland consisting of a flat-topped plateau ("Fish Lake Hightop"; 3547 m) west of the Fish Lake graben, a gently southeastward-sloping plateau surface east of the graben, and more irregular high ground east of Seven Mile Valley, which includes Mounts Terrill, Marvine, and Hilgard. This upland is underlain by calc-alkaline lava flows (Rowley et al., 1979). Hardy and Muessig (1952) described two sets of moraines, attributed to the "Wisconsin I and II" (early and late Wisconsinan) glaciations in vogue at the time. The younger of these sets is typified by the steep-fronted, 90–120-m-thick lobe-moraines west and northwest of Widgeon Bay (Fish Lake) (Fig. 23); another excellent example is the "Moraine Valley" deposit east of Mt. Terrill, described by Dutton (1880). We agree with Hardy and Muessig (1952) that these are late Wisconsinan or Angel Lake in age. The longest valley glacier (Tasha Creek, on the east flank of the Hightop) was at least 8 km long, and it may have emanated from a fairly broad icecap. Although Hardy and Muessig's "ice eroded features" on the Hightop (p. 1113) are not evident on air photos and could not be verified on the ground, the heads of Tasha Creek and Pelican Canyons are very broad, shallow depressions that merge gradually with the plateau top; there is no distinct upper limit of ice.

Remnants of pre-Angel Lake moraines are most obvious below the Sevenmile Cirques on the north end of the Hightop, and below two unnamed cirques northwest of Widgeon Bay (Fig. 23). These moraines are looping ridges, relatively small in transverse cross-section. They extend 0–600 m beyond the younger moraines. Some remants that apparently are reasonably well preserved suggest that the moraines had much less original volume than the Angel Lake moraines. Hardy and Muessig (1952) report that boulders on the older moraines are more weathered.

Fig. 24. Talus-derived rock glacier (front marked by arrows) overlying hummocky cirque moraine on the east side of Mt. Terrill, a satellite of Fish Lake Mountain.

Cirque deposits, mainly in the form of rock glaciers, are common. Younger rock glaciers are superimposed over older ones in the largest of the Sevenmile Cirques, in the northernmost of the two cirques northwest of Widgeon Bay, and on the east side of Mt. Hilgard. On the east side of Mt. Terrill a rock glacier is superimposed over a hummocky, lobate cirque moraine (Fig. 24). Field examination at the Terrill and Widgeon Bay cirques indicates there is no significant weathering differences between older and younger cirque deposits. Volcanic boulders in both sets are sufficiently weathered (minor cavernous weathering, disintegration along fractures, partly weathered-off patina) to suggest that pre-Altithermal ages are likely.

The Sevier Plateau, usually broken into northern and southern units, is a long upland with a more irregular top surface than surrounding plateaus. High points are Monroe Peak in the north (3427 m) and Mt. Dutton in the south (3366 m). The plateau is underlain by a variety of flow, volcaniclastic, and tuffaceous rocks; dacite flows predominate in the Monroe Peak area (Callaghan and Parker, 1961; Cunningham et al., 1983). Definite evidence of glaciation is found only around Monroe Peak. A narrow, lobate Angel Lake moraine heads north of the peak (Serviceberry Creek drainage) and extends down to 2660 m elevation; the glacier was 2 km long. Beyond the lobe front, two well-preserved laterals of a pre-Angel Lake glaciation extend down to 2380 m. These deposits together are shown as "Qg" (glacial deposits) on the map of Cunningham et al. (1983), although the map incorrectly shows some morainal deposits in the cirque (including a small cirque moraine) to be landslide deposits. A glacier of indefinite extent headed in the cirque northeast of Monroe Peak and there may have been some ice on the west flank.

The Markagunt Plateau, underlain in part by volcanic flows, rises to 3447 m at Brian Head. South of Brian Head a steep, dissected embayment in the plateau edge constitutes "Cedar Breaks", where the Claron Formation is exposed (Moore and Nealey, 1993). Gregory (1950) briefly mentioned glacial features along Castle Creek, and Mulvey et al. (1984) and Currey and Mulvey (1986) reported evidence for Pleistocene plateau-top glaciers of 4 and 5 km length along Lowder Creek and Castle Creek, respectively. A radiocarbon age of 14,400 $\pm$ 850 yr BP (UCR-1661) from bulk organic mud at Lowder Bog is a minimum for deglaciation (Mulvey et al., 1984). These authors note (p. 99) that the two drainage basins "show remarkably little evidence of sculpting by glacial erosion"; indeed, observations by Osborn indicate no such evidence. Yet there is little doubt that the lobate, hummocky deposits mapped by Mulvey et al. (1984) are terminal moraines, although the Lowder Creek moraine does not have a distinct downstream limit. These glaciers were probably shallow accumulations transitional between valley glaciers and small ice caps. We agree with the previous workers that the moraines are of late Wisconsinan age. Mulvey et al. (1984) suggest that bouldery surfaces just downstream of the moraines may represent an older glaciation, and that the plateau divide north of the head of Castle Creek may have been occupied by an ice cap at one time.

More recently, Agenbroad (1996) and Agenbroad et al. (1996) have suggested that ice flowed from the southwest side of Brian Head to the rim of Cedar Breaks, based on the presence of a diamict immediately overlying the Claron Formation along the rim and erratics near the rim, as well as a source cirque and associated moraines near the summit of Brian Head. However, the Markagunt Megabreccia, a gravity-slide deposit of Miocene age, overlies the Claron Formation in the region (Hatfield et al., 2000b), and is explicitly described as occurring near the Cedar Breaks rim (Hatfield et al., 2000a) and associated talk). Considering that neither group of authors seems to be aware of the other's work, and that the megabreccia at Cedar Breaks is described as unconsolidated, on the order of meters thick, consisting mostly of large blocks and boulders, and occurring at the surface, it is possible that both groups are examining the same deposit and interpreting it differently. Further work is needed before glaciation at Cedar Breaks is confirmed.

If there was ice on the plateau surface there must have been ice on the less exposed northwest flank of the plateau. There is hummocky topography on the flank, but much of it seems to be products of slumping of slices of bedrock, and other forms of mass movement. There is no obvious glacial limit. Small rock glaciers mantle slumped slices west and north of Brian Head and northwest of Sidney Peaks.

Flat-topped Boulder Mountain, with a high point of 3450 m, is the highest level and eastermost part of the Aquarius Plateau. The misnamed "mountain" is underlain by Tertiary basalts, but the glacier ice that collected in cirques below the rim flowed not over intact bedrock but over a variety of collapsed slices of cliff, hummocky slump masses, and assorted colluvial deposits that mantle the slopes around the plateau. The glacial geology was described by Gould (1939) and Flint and Denny (1958); the latter's interpretations were reproduced mostly intact by Smith et al. (1963) and in a more recent regional map of Billingsley et al. (1987). One of Flint and Denny's lateral moraines has been recently dated cosmogenically by Marchetti and Cerling (2000).

Both Gould (1939) and Flint and Denny (1958) agree that an ice cap mantled part of the plateau, judging from streamlined erosional forms oriented in a radial pattern, and discharged in places over the rim. Gould did not map deposits, but noted a lack of moraines below 2728 ft elevation. Flint and Denny mapped deposits below the rim, dividing them into Blind Lake ("younger Pinedale(?)"), Donkey Lake ("older Pinedale(?)") and Carcass Creek ("Bull Lake(?)") units. Although there is some support for this subdivision, we disagree with some of the mapping. The Blind Lake limit is distinct around Blind and Fish Creek Lakes and in the compound cirque 6 km southwest of Chokecherry Point, but appears to be only a break in slope, or less, at the mapped positions around Green Lake and west to the Donkey Creek headwaters, and in the cirques east and west of Trail Point. It is debatable whether these mapped deposits indeed constitute a distinct mappable unit; more likely there are Late Wisconsinan recessional moraines in some drainages but not others.

The Donkey Creek unit could be construed to be a set of lightly dissected, generally lobate moraines representing a significant advance of glaciers a few km out from the rim, probably of Angel Lake age judging from morphology ("Pinedale" age using the terminology of Flint and Denny) (Fig. 25). However, some of Flint and Denny's terminal positions appear to be mislocated (Table 2). With the amendments of Table 2, we agree that the Donkey Creek moraines are of Pinedale, or Angel Lake, age. Somewhat anomalous is the Donkey Creek moraine mapped by Flint and Denny along Fish Creek, which terminates about twice as far from the rim (over 6 km) and at a lower elevation (2590 m) than other nearby examples. The deposit is composed of bouldery diamict but there are no good exposures. Geomorphically it could be either a lobate ablation moraine into which lateral moraines grade, or a large debris flow with lateral levees. The latter is suggested by the wide, flat (as opposed to U-shaped) valley bottom between the lateral ridges. There is not, however, any other obvious upstream candidate for a Donkey Creek terminal position, and the high ridges bounding Hickman Pasture indeed appear to be lateral moraines. They are interpreted to be moraines by Waitt (2000), and one of the crests at Hickman Pasture was sampled by Marchetti and Cerling (2000) for ^{3}He dating. Preliminary ages for three boulder

Fig. 25. Angel Lake moraine (arrow)(Donkey Creek Drift of Flint and Denny (1958)) in the vicinity of Blind Lake, seen from a point on the Boulder Mountain rim due west of Blind Lake.

surfaces are $16{,}100 \pm 1600$, $19{,}000 \pm 1900$, and $20{,}900 \pm 2100$ cosmogenic years, respectively, suggesting that the ridges are products of Pinedale glaciation.

Flint and Denny's (1958) oldest glacial unit, Carcass Creek drift, probably does not really exist. There is no particular morainal morphology in the mapped Carcass Creek deposits south of Trail Point or along Pleasant Creek southeast of Chokecherry Point, and it is very difficult to distinguish glacial from colluvial deposits on the forested slopes. The Carcass Creek deposit along Fish Creek is shown as extending all the way to the Fremont River at 2010 m elevation, 14 km from the rim, at least partly because of interpretation of a diamict along the river as till (photograph in Smith et al. (1963)). In air photos this deposit is seen to consist mostly of irregular longitudinal ridges. Defining the east side of the lobe are well-preserved parallel ridges, as many as four in number. These ridges, along with the general longitudinal grain and downvalley distance and elevation, suggest that the deposit is a massive debris flow, an interpretation not inconsistent with the nature of the diamict along the river. An independent look at the Carcass Creek deposits has recently been taken by Waitt (2000); he also interprets them as debris flows. In summary, we believe that although there *could* be pre-Angel Lake deposits around the plateau, there is no definitive evidence for such deposits.

Rock glaciers are common at the heads of cirques below the rim. Boulder weathering on them is similar to that of the Angel Lake deposits, so the rock glaciers are probably pre-Altithermal in age.

2.12. Southwestern Utah Ranges

The Pavant and Tushar ranges are adjacent to the Utah Plateaus, but consist of a narrow fault-block range and a group of dissected volcanic peaks, respectively.

Table 2
Elevations (m) of Angel Lake-age Glacial Termini around Boulder Mountain

	Donkey Creek	Spring Creek	Fish Creek	Pleasant Creek	Boulder Creek
This study	2880	3050	?	2650	2685
Donkey Creek Drift of Flint and Denny (1958)	2755	3050	2560	2500	2500

The Pavant Range consists of a variety of Paleozoic and Mesozoic sedimentary rocks capped in part by Cretaceous and Tertiary sedimentary and volcanic rocks (Baer et al., 1982). Cirques along the crest are developed mainly in sandstones, siltstones, and shales. The range rises to 3114 m at White Pine Peak. Pleistocene glaciers eroded cirques along the crest in the vicinity of White Pine Peak, and between Jack's Peak and Peak 10042 to its north. In the latter area, moraines in Robins Valley were mentioned by Tucker (1954) and Oviatt (1992). We concur with Oviatt that the most obvious moraine in the valley, a lobate, steep-fronted terminal moraine deposited by a 2.3-km-long glacier, is of late Wisconsinan (Angel Lake) age. An apparent recessional moraine lies 1.2 km upstream, and a small cirque moraine extends a few hundred meters from the headwall due west of Robins Lake. Similar Angel Lake moraines are found in the drainages of Pharo Creek, and Eagle Hollow, and on the north side of White Pine Peak in the headwaters of Bear Canyon.

The Tushar Mountains, part of the Marysvale Volcanic Field, is a volcanic plateau surmounted by the crests of several large volcanoes. The higher parts of the range are underlain by a variety of flows and tuffs of intermediate to rhyolitic composition; these rocks as well as basalt occur at lower elevations (Steven et al., 1979; Cunningham et al., 1983). The range crest averages 3500 m elevation, and Delano Peak rises to 3710 m.

Relative to those in other ranges, Pleistocene moraines here are not very distinct. However, sufficient morainal material is preserved to suggest that much of the area around Delano Peak, Mt. Belknap, Copper Belt Peak, and Gold Mountain supported glaciers. The best preserved deposits were deposited by valley glaciers generally 3–4 km long (e.g., Fig. 26). Mean PDI's of soils on the deposits, as compared to PDI's of chronosequences of Harden and Taylor (1983), are consistent with a late Pleistocene (Angel Lake) age (Bevis, 1995). Apparent blankets of diamict extending beyond the Angel Lake moraines, mostly devoid of morainal morphology, are suggestive of an older glaciation. PDI's of soils developed on these deposits suggest an age range of 10,000 to a few hundred thousand years for these deposits.

Cirque moraines and rock glaciers are common in the Tushars. On the northeast flank of Mt. Belknap there are two such deposits, an upper rock glacier and a small moraine 125 m elevation below it. A mining road cut through the front of the rock glacier shows that clasts within 0.5 m of the surface of the deposit are stained brown from weathering. The weathering and the rounded front of the rock glacier, sloping at less than the angle of repose, suggest a pre-Altithermal age for it and the moraine below it.

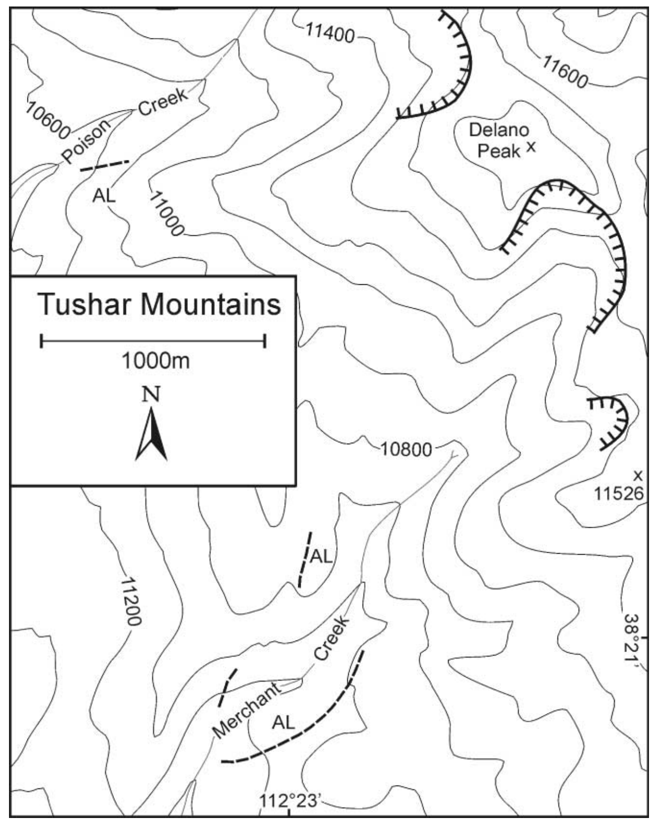

Fig. 26. Moraine positions along Merchant and Poison Creeks in the Tushar Mountains. Source base maps: Delano Peak, Shelly Baldy Peak (Utah), 1 : 24,000 scale.

2.13. Utah/Nevada Border Ranges

Close to and on either side of the Utah/Nevada border are the Deep Creek and Snake Ranges, remarkable for their height and featuring alpine topography like that in the Ruby Mountains, but over more modest areal extent.

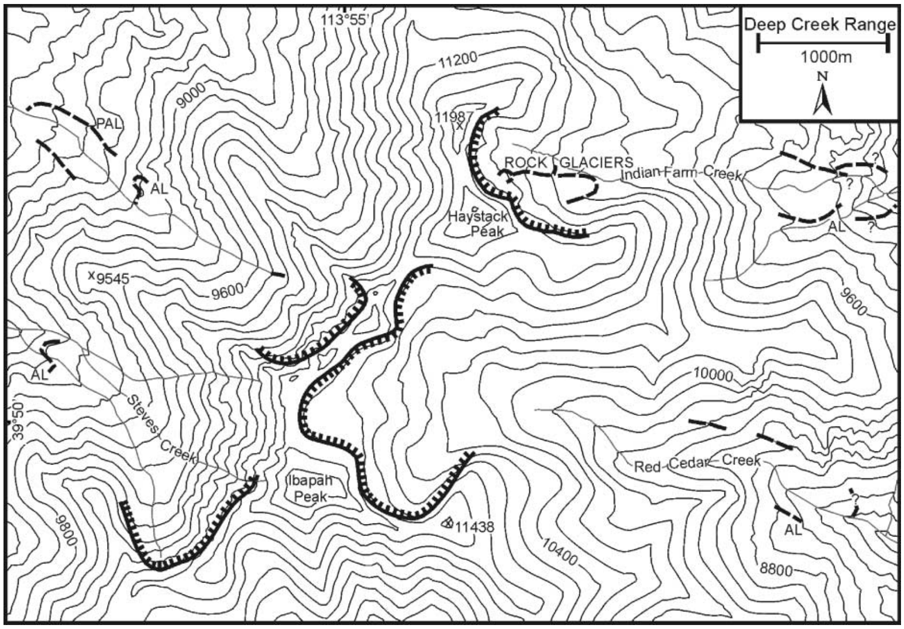

Fig. 27. Moraine positions around the highest peaks of the Deep Creek Range. Source base maps: Ibapah Peak, Indian Farm Creek (Utah), 1 : 24,000 scale.

The southern Snake Range (SSR) harbors the only remaining glacier ice in the GB east of the Sierra Nevada.

The Deep Creek Range of Nevada rises abruptly from the west and more gently from the east to a maximum elevation of 3684 m at Ibapah Peak. The range is underlain by Precambrian and Paleozoic metasedimentary and metavolcanic rocks, intruded by granitic rocks which crop out along the high crest of the range (Robinson, 1987; Gans et al., 1990). Bick (1958) mapped undifferentiated glacial deposits during general geologic mapping, and Bevis (1995) distinguished two ages of valley moraines and a younger set of cirque moraines using relative dating. Glaciers were present from Toms Creek in the north down to the head of Trout Creek, south of Red Mountain.

Bevis' drift unit II, interpreted to be of Stage 2 late-glacial-maximum age, is here grouped with the Angel Lake deposits noted in other ranges. Indeed, most of these moraines are lightly dissected and lobate, similar to those in other ranges. Exceptions are the two longest reconstructed Angel Lake glaciers, extending down Indian Farm and Red Cedar Creeks, respectively (Fig. 27). In the former case, discontinuous remnants of lateral moraine indicate the glacier descended at least to 2670 m, but the terminal position is difficult to identify. In the latter case, preserved remnants of lateral moraines indicate the glacier terminated at approximately 2450 m.

Isolated lateral-moraine remnants of an older glaciation occur along Steves Creek and Toms Creek, and well-preserved older laterals occur along the unnamed creek south of Sams Creek. These are assigned to drift unit I by Bevis (1995), and relative-age parameters, in addition to physiography, suggest these deposits are older than those of drift unit II.

Fig. 28. Looking downstream from the cirque at the head of Indian Farm Creek. A small rock glacier of probable Neoglacial age (front marked by arrow) is superimposed over an older (pre-Mazama tephra) rock glacier (mostly bare but with a prominent clump of trees). The older deposit is part of Bevis' (1995) Drift Unit III.

Cirque moraines (drift unit III) sampled by Bevis (1995) have similar weathering characteristics to those of unit II, and are interpreted on that basis to be of latest Pleistocene or early Holocene in age. This assignment is corroborated by independent recovery, by Osborn, of Mazama tephra overlying the southernmost of two drift unit III rock glaciers at the head of Indian Farm Creek. One of those two rock glaciers is overlain by a still younger, small rock glacier (Fig. 28). The younger deposit is treeless, with few fines and no overlying tephra, and its boulders less weathered than those of the older rock glacier (e.g. rather smooth boulder faces on the younger vs. 2.5-cm feldspar protrusions on the older). This younger deposit likely represents a Neoglacial advance.

The Snake Range is usually subdivided into a northern massif topped by Mt. Moriah at 3674 m elevation, and a more extensive southern range capped by Wheeler Peak, 4285 m elevation. Both parts are underlain mainly by early Paleozoic quartzite, limestone, and shale, metamorphosed in part and dotted with a few small granitic intrusions (Hose and Blake, 1976; Miller and Grier, 1993).

Gilbert (1875), Russell (1885), and Blackwelder (1931) all noted glacial features in the SSR. More recently, two ages of Pleistocene moraines are mentioned by Wayne (1983) and mapped by Piegat (1980), using Angel Lake/Lamoille terminology, and described by Drewes (1958) and Waite (1974), using Tioga/Tahoe terminology. Piegat's map (with which we generally agree, apart from its Angel Lake positions on Lehman and Baker Creeks) indicates that compound valley glaciers flowed down Lehman, Baker, and Snake Creeks, and small independent glaciers occurred as far north as the north flank of Bald Mountain and as far south as the north side of Granite Peak. All glaciers were on the east side of the crest, except on the northeast side of Mt. Washington and in upper Williams Canyon. We concur with interpretations of two major glaciations; the younger (Angel Lake) is well represented by the hummocky, bulky, lobate Dead Lake moraine, ESE of Johnson Lake. Angel Lake ice descended to elevations between 2650 and 2850 m in the major drainages (Fig. 29). The older glaciation is represented by a dissected moraine descending from east of Dead Lake to immediately west of the Shoshone Campground, by the lateral moraine that follows part of the South Fork Baker Creek trail, and by the morainal ridges that terminate a few hundred m west of Upper Lehman Creek Campground. Ice during this advance descended to between 2440 and 2530 m in the major drainages, and the longest glaciers were about 6 km long (Fig. 29).

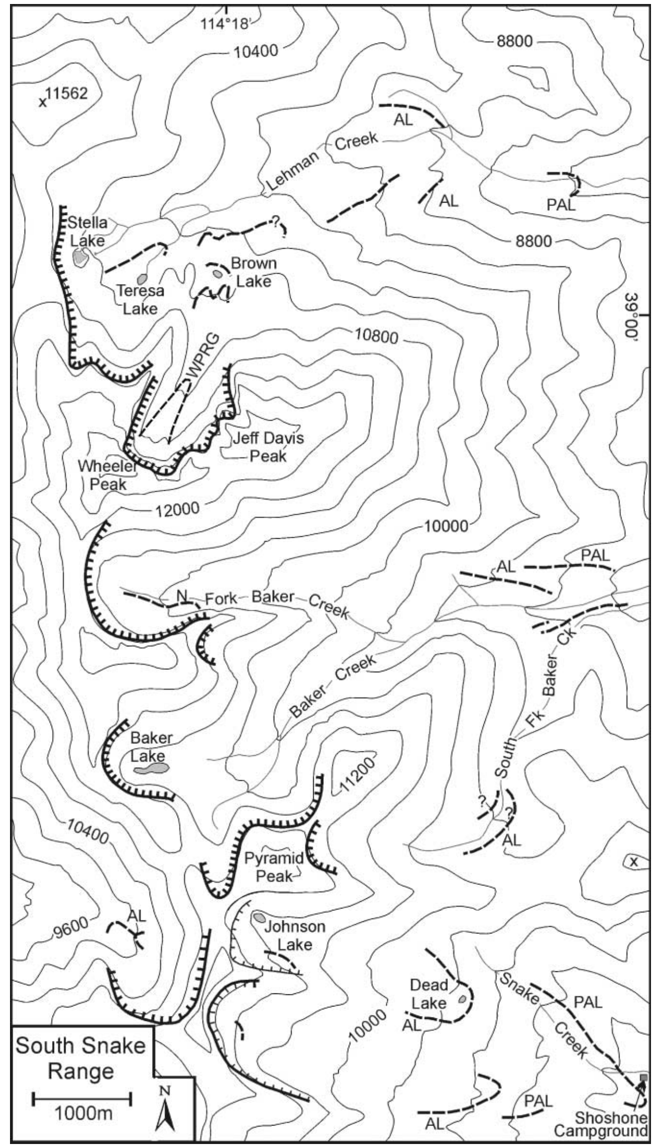

Fig. 29. Moraine positions along Lehman, Baker, and Shoshone Creeks in the South Snake Range. WPRG: Wheeler Peak rock glacier. Source base maps: Wheeler Peak, Windy Peak (Nevada), 1:24,000 scale.

The most dramatic glacial features in the SSR, and indeed in the central Great Basin, are on the north flank of Wheeler Peak, where a very deep cirque shelters a 900 m-long, tongue-shaped body of snow, ice, and rock debris (Fig. 30) which has been the source of much descriptive confusion. The first written account of the glacier ice at the head of this body was by W. Eimbeck in 1883 (reported by Russell, 1885); the ice was then "rediscovered" by Heald (1956), and further described by Lawrence (1958), Kramer (1962), Currey (1969), Waite (1974), and Osborn (1990). In the early papers, early letters on the subject, and US. Forest Service literature the ice is variously referred to as a "body of ice … that approaches the condition of a glacier", a "glacieret", an "ice mass", an "active glacier", and an "icefield", and the hummocky rubble downstream of it is described as "moraine tongue", "mound of unstable moraine", "rock deposit", and "rock glacier" (Osborn, 1990). Waite (1974) claimed that the glacier enlarged between 1883 and 1956 and that the upper part of the rock glacier was actively moving (at the time of his writing), but offered no evidence. Meanwhile, an unpublished document by rancher J.F. Griggs, Jr. (undated, but post-1985) arguing against establishment of Great Basin National Park claims that the glacier is not permanent: "Investigators during the summers of 1931, 1934, and 1978 found no trace of it. No ice, no snow, not a drop of water to drink." All these claims are discussed, and discounted, by Osborn (1990). Presently,

Fig. 30. Wheeler Peak rock glacier as seen from the summit of Wheeler Peak. Terminus of the upper segment is marked by large arrow and of the lower segment by small arrow.

Fig. 31. Bergschrund of the very small glacier at the head of the Wheeler Peak rock glacier. Normal-fault-type displacement of the glacier surface across the bergschrund in the 1990s indicates that the glacier is still (barely) active.

the exposed ice at the base of the cirque headwall is perennial and deforms under its own weight, and hence can be considered to be a glacier, but it is rapidly disappearing as a result of a strongly negative mass balance. Winter snow normally retreats almost to the bases of the headwall gullies, making the snowline approximately 3460 m in elevation. Motion of the glacier ice is indicated by vertical offsets of the glacier surface across the bergschrund (Fig. 31). The glacier grades into an ice-cored rock glacier downstream. The upper segment of the rock glacier has a front at the angle of repose and a sharp front/top angle, suggestive of recent motion, but comparison of ground photographs from the 1950s and 1970s to the modern front shows no displacement of prominent rocks. The lower segment of the rock glacier has a hummocky surface, rounded front, and convex-up transverse cross-section; it is probably ice-cored as well. Lichen cover and proximity to the modern snowline indicates a Little Ice Age origin of the upper segment, while glass shards of Mono Craters origin incorporated into the matrix of the lower rock glacier indicates a pre-1200 AD origin of that segment (Osborn, 1990). Although the SSR is barely within the fallout area of Mazama tephra drawn by Sarna-Wojcicki et al. (1983), no Mazama was found anywhere in the range.

Between the Wheeler Peak rock glacier and the Angel Lake moraine on Lehman Creek are three intermediate end moraines. At least some of these are probably latest Pleistocene in age, but the quartzite boulders in them are not conducive to relative dating. Cirque moraines occur west of Teresa Lake and in the Baker Creek and Snake Creek drainages.

The only known previous glacial investigations of the Northern Snake Range are those of Piegat (1980), who mapped undifferentiated glacial deposits in four valleys, and D. Clark (personal communication, 1998), who mapped undifferentiated glacial deposits in the valley trending northward from Mt. Moriah, during a 1982 field camp. In the present study a lateral/terminal loop near the head of the valley north of Mt. Moriah is regarded as a probable Angel Lake moraine (Fig. 32). A forested, rounded bench downstream may be a deposit of an older glaciation. A small rock glacier extends into the forest above the Angel Lake moraine. It has a rounded front and bears a few trees and hence has not been recently active, but it is clearly younger than the Angel Lake moraine on both stratigraphic and boulder-weathering grounds (D. Clark, personal communication, 2000).

Valleys heading on the north and east sides of The Table were probably glaciated but there are no obvious terminal limits.

2.1.4. East-Central Nevada Ranges

The east-central Nevada ranges consist of the Schell Creek, White Pine, and Grant Ranges.

The long, narrow Schell Creek Range, rising to 3623 m at North Schell Peak, is underlain by the same Paleozoic stratigraphic units as the Snake Range (Hose and Blake, 1976), and most moraines are composed of a majority of quartzite clasts and a minority of limestone clasts. Both Gilbert (1875) and Blackwelder (1931) noticed glacial features in the range, and Piegat (1980) mapped moraines he assigned to Neoglacial, Angel Lake, and Lamoille advances. We are in general agreement with the extent of glaciation noted by Piegat (from 3 km north of North Schell Peak south to Cleve Creek Baldy), but disagree with some of his Angel Lake terminal positions, which are not obvious either in the field or on air photos. His reconstructed Neoglacial ice east of South Schell Peak (the two branches of Taft Creek) is too extensive and low-elevation to be consistent with his other Neoglacial glaciers, and his Taft Creek limits are here interpreted to

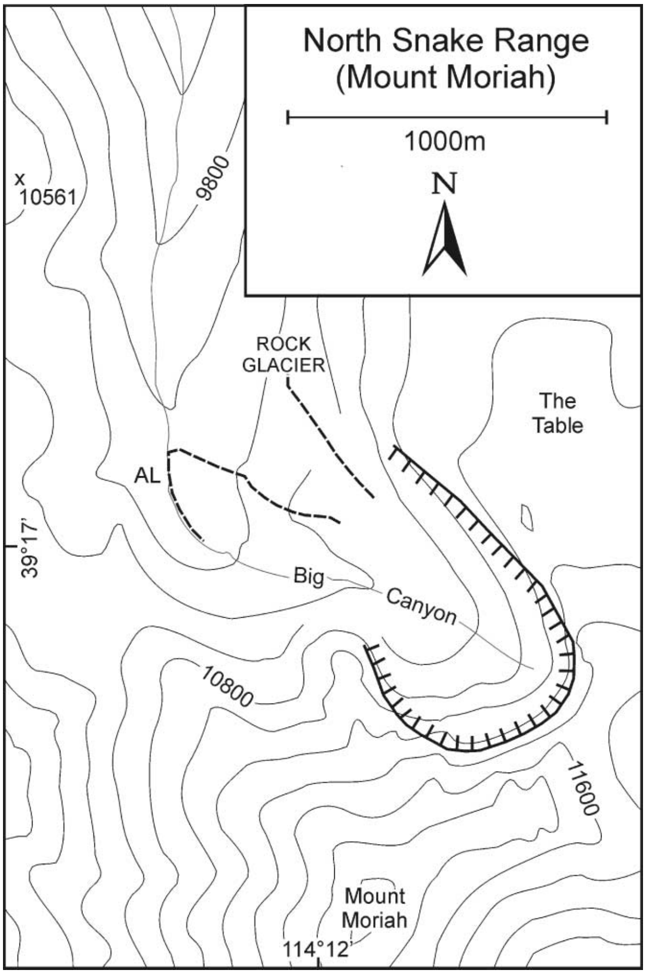

Fig. 32. Moraine positions along Big Canyon in the North Snake Range. Source base map: Mt. Moriah (Nevada), 1 : 24,000 scale.

be Angel Lake limits. The Angel Lake moraines here as elsewhere in the range tend to be moderately thick, lobate forms. The longest Angel Lake glaciers were about 2 km long. Along Taft Creek partially preserved lateral moraines extend 2 km farther downstream than the Angel Lake moraines (Fig. 33), indicating an older glacier (Piegat's "Lamoille") was approximately twice as long as the Angel Lake glacier. The cirque moraines common in the range are at low elevations relative to interpreted Neoglacial deposits in the nearby Snake Range, and are probably pre-Altithermal in age.

The modestly glaciated White Pine Range rises to 3510 m at Currant Mountain. Cambrian through Tertiary sedimentary and volcanic rocks crop out in the range; glaciated valleys are underlain mainly by limestone (Hose and Blake, 1976). Piegat (1980) mapped moraines in the range, and noted that Lumsden (1964) and Moores et al. (1968) misattributed glacial deposits to other types of Quaternary sediments, which mistake was incorporated into later county and state maps. Piegat reconstructed three Angel Lake glaciers heading in three cirques on the east side of the Currant Mountain crest. In addition to those there is a fourth, which extended NNW from Peak 11154. This latter glacier and the one descending from the compound cirque below Peak 11413 constructed well-preserved, lobate terminal moraines typical of Angel Lake deposits. Glaciers descending from Currant Mountain and from Peak 11273 did not leave obvious terminal moraines of any age. Piegat shows Angel Lake moraines at relatively high elevations but moraines at these sites are not discernable on our air photos. The two glaciers coalesced below 2775 m and constructed lateral moraines which are now partly preserved. Piegat regarded this coalesced glacier as Lamoille in age, but we are uncertain whether it is pre-Angel Lake or Angel Lake in age.

The Grant Range, whose crest is underlain by Cambrian/Ordovician limestones, cherts, shales, and phyllites (Cebull, 1970), rises to a fairly high elevation at Troy Peak (3445 m), but is at a sufficiently low latitude that only one moraine was constructed, at the northwest base of Troy Peak. It is a hummocky, lobate mass interpreted to be of Angel Lake age. The reconstructed glacier was 0.5 km long.

3. Discussion and conclusions

We have identified evidence for Pleistocene glaciation in 40 individually named ranges, plateaus, and massifs draining wholly or partly into the GB, including the Sierra Nevada and Wasatch Range. A 41st range, the Spring Mountains, is a contender. The most obvious deposits are the family of moraines designated "Tioga" by Blackwelder (1934), "Angel Lake" in the Ruby Mountains by Sharp (1939), "Pinedale" in the Wasatch Range by several authors, "Group II" in the Toiyabe Range by Osborn (1989), and "Perry Aiken" in the White Mountains by Elliot-Fisk (1987). Such moraines generally can be followed from range to range away from described type moraines such as the Angel Lake moraine, although ambiguity persists in some ranges where glaciers were very small, such as the Pine Forest Range and Sweetwater Mountains. Angel Lake-equivalents have been numerically assigned to late Wisconsinan glaciation in the Wasatch Range, White Mountains, Sierra Nevada, and Boulder Mountain on the basis of radiocarbon and surface-exposure dates (as described above) and have been assigned to late Wisconsinan in several other ranges by Bevis (1995) and in the Ruby Mountains by Wayne (1984) on the basis of relative-age studies. In addition, there is the obvious point that these deposits in general constitute the stratigraphically youngest or most-upstream significant valley-glacier deposits.

The type Angel Lake moraine is not so much a looping ridge, like the end/lateral moraines diagrammed in textbooks, as it is a thick, hummocky, lobate pile of till. This

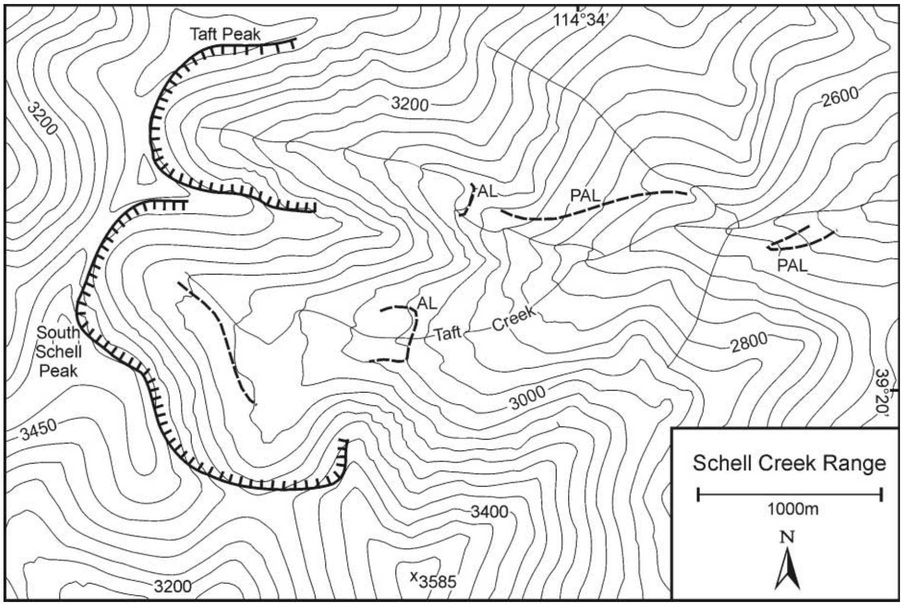

Fig. 33. Moraine positions in the Taft Creek drainage of the the Schell Creek Range. Source base map: South Schell Peak (Nevada), 1 : 24,000 scale.

description applies to most equivalent deposits all across the GB, so much so that there may be some climatic significance to the form. Such moraines must be formed by glaciers carrying much sediment sub- or superglacially, and the thickness of the moraines (often 60 m or more) suggests either that the glaciers remained at their terminal positions for long periods of time, or that the glaciers advanced, retreated, and readvanced to the same positions a number of times. A possible explanation is provided by the work of Benson et al. (1996) and Benson et al. (1998) on lake sediments in the Owens Lake basin. These authors interpreted variations in magnetic susceptibility and organic carbon content of the sediments to indicate that about 19 "glaciations" occurred in the Sierra Nevada between 52,500 and 23,500 yr BP, and that there may be some correlation between these glacial advances and the Dansgaard-Oeschger cycles and Heinrich events known from the North Atlantic. Phillips et al. (1996) used cosmogenic dating to suggest that sets of 4 Tioga moraines in the Sierra can be related to Heinrich events, and that there may have been other moraines constructed during other Heinrich events that were destroyed by subsequent advances. It is conceivable that the Angel Lake glaciers of the GB similarly oscillated, but tended to readvance to about the same positions each time, so that thick, bulky moraines were constructed rather than sequences of ridges. However, there is no present evidence to rule out a competing possibility that the bulky moraines resulted from simple, long-lived advances of sluggish, heavily debris-charged glaciers.

Valleys in most of the ranges of the GB each contain only one moraine which on weathering or morphological grounds would be considered "Angel Lake". But in the White Mountains there are two prominent Angel Lake moraines, distinct in elevation and downvalley extent, in at least some valleys. West of there, in the Sierra Nevada, some valleys have multiple Tioga moraine loops, and some so-called "Tenaya" deposits may be relatively old Late Wisconsinan deposits. The multiple Late Wisconsinan moraines in the Sierra and White Mountains suggest that climatic controls on Late Wisconsinan glacier behavior were different along the southwestern margin of the GB than they were elsewhere in the GB.

Pre-Angel Lake deposits, designated "Lamoille" in the Ruby Mountains, "Indian" in the White Mountains, "Group III" in the Toiyabe Mountains, and "Bull Lake" in the Wasatch Range, occur in many GB ranges. However, it is difficult to tell if these deposits are equivalent to each other and what their relationship is to pre-Tioga deposits in the Sierra. The term "Lamoille" has come to be used in many reports (including this one) for moraines that extend farther downstream, and appear to be older, than Angel Lake moraines, but there could be different ages of deposits which meet this description. The only well-established numerical age for a pre-Angel Lake deposit is the radiocarbon minimum of ca 26,000 yr BP for the Bull Lake moraines at the Wasatch Front (Madsen and Currey, 1979). Zreda and Phillips (1995) provided ^{36}Cl ages of 150,000 and $>$ 150,000 yr BP for Indian and Dyer deposits in the White Mountains, but the former age may not be very accurate because of boulder erosion, and in any event it has not been well established that the dated deposits are of glacial origin. Bevis (1995) attempted to relate deposits to known ages and oxygen-isotope stages by comparing weathering rinds and soil PDIs to published rind and PDI data from independently dated surfaces, and found some inconsistency: pre-Angel Lake moraines in the Strawberry and Deep Creek Mountains relate best to Stage 4, Ruby Mountain moraines seem to be of Stage 6 age, and Steens, Pine Forest, and Tushar moraines may relate to either 4 or 6 or somewhere in between, or perhaps a combination thereof. Considering the general paucity of organic matter and the long exposure to weathering of these old deposits, it may never be possible to accurately date them with currently known techniques.

It is difficult to reconstruct accurately the lengths of the older glaciers because in many cases there is no terminal-moraine morphology left and terminal positions must be estimated from till sheets and/or erratics or by projecting lateral moraines. Fig. 34 shows examples of preserved pre-Angel Lake moraine remnants relative to reconstructed Angel Lake limits. In general, pre-Angel Lake glaciers were significantly longer than their younger counterparts; in the unnamed Fish Lake Mountain drainage, the older glacier was twice as long as the younger. These length differences do not translate into great differences in ELA depression however, because the older, longer glaciers tended to terminate on piedmonts and so had low gradients in their lower reaches. In cases where the older moraines are moderately well preserved, it is evident that they are less bulky and lobate than Angel Lake moraines, and more like the looping ridges described in textbooks (e.g., Fig. 23). It is possible that the pre-Angel Lake glaciers spent less time at their terminal positions than did the later glaciers; however, at least some of the *apparent* lesser volume of the older moraines is due to fact that the morainal debris is spread over a larger area.

As for post-Angel Lake deposits, a general conclusion is that there were minor, pre-Altithermal advances that were more extensive than Neoglacial advances. Such is the case in the Sierra Nevada west of the GB, and in various Rocky Mountains ranges to the east of the GB, while in the Canadian Rockies the LIA advance at most sites was more extensive than latest Pleistocene advances (Osborn and Luckman, 1988). A second generalization is that the ELA was sufficiently high in the latter parts of Holocene time that only the highest, wettest ranges developed Neoglacial ice (Sierra Nevada, Steens, Wasatch, Deep Creek, Snake, and possibly Sweetwater and Toiyabe). Of the five relatively certain cases, one (Sierra Nevada) has only LIA moraines representing Neoglacial time, whereas the Snake and Wasatch Ranges apparently sustained an earlier Neoglacial as well as LIA advance. In the case of Steens Mountains there *may* have been an earlier Neoglacial advance in addition to the LIA advance, while in the Deep Creek Range the interpreted Neoglacial advance may or may not belong to the LIA.

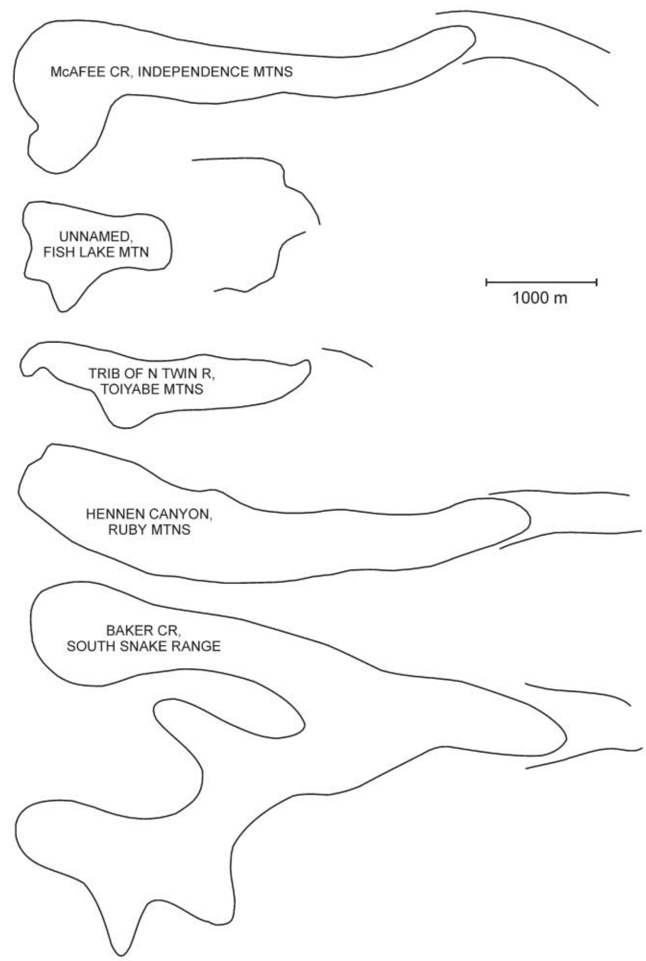

Fig. 34. Examples of reconstructed Angel Lake glaciers in the Great Basin (closed outlines), showing their relations to pre-Angel Lake moraine remnants.

Many GB ranges have cirque moraines or rock glaciers interpreted to be of pre-Altithermal age (i.e., latest Pleistocene or early Holocene) because of overlying Mazama tephra or weathering comparisons to local Angel Lake moraines. Several ranges (White, Santa Rosa, Independence, Jarbidge/Copper, Fish Lake, Tushar, and conceivably Wasatch) are interpreted to have at least one cirque each featuring two pre-Altithermal moraines and/or rock glaciers, some related through superposition. Two ages of pre-Altithermal advance are particularly well established on the East Fork of Mill Creek in the Independence Range, where one of two small cirque moraines is overlain by Mazama ash and in turn overlies the second small moraine (the older moraine presumably was dusted with Mazama as well but no suitable collecting basins were found on it). Considering that pre-11,000 yr BP advances have been described from the Sierra (Clark and Gillespie, 1997) and northern American Rockies (Osborn and Gerloff, 1997) and that 11,000–10,000 yr BP (Younger Dryas-aged) deposits have been described from the Canadian Rockies (Reasoner et al., 1994) and Colorado Rockies (Menounos and Reasoner, 1997), we suggest as a working hypothesis that advances of these two ages were responsible for the two sets of pre-Altithermal moraines in some GB ranges. In ranges with only one known set of such moraines (e.g., Ruby, Pine Forest, Stansbury), it is impossible, at this time, to know which advance they might belong to, assuming the above hypothesis is correct. This ambivalence also applies to the cosmogenically dated 11,000 yr old moraines in the White Mountains. But even without known numerical ages for the pre-Altithermal deposits, it is clear that there were differences in glacial successions along a west–east transect through the Cordillera: there is only one latest Pleistocene advance known from the Sierra Nevada, even in lake sediment records (Clark and Gillespie, 1997), while to the east there was more than one, at least in some places. Lake sediment studies in ranges east of the Sierra Nevada will presumably help to clarify the glacial history.

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References

Agenbroad, L.D., 1996. Late Pleistocene glaciation in southeastern Utah national parks: Cedar Breaks and Zion. Field Trip Guidebook for American Quaternary Association Biennial Meeting, Northern Arizona University, Flagstaff, Arizona.

Agenbroad, L.D., Brunelle, A., Ort, M., 1996. The Mammoth summit glacier, Iron County, Utah. Program and Abstracts of the 14th Biennial Meeting of the American Quaternary Association Meeting, May 20–22, p. 146.

Anderson, J.J., Rowley, P.D., 1975. Cenozoic stratigraphy of southwestern High Plateaus of Utah. In: Anderson, J.J., Rowley, P.D., Flack, R.J., Nairn, A.E.M. (Eds.), Cenozoic Geology of Southwestern High Plateaus of Utah Boulder, Colorado. Geological Society of America Special Paper 160, pp. 1–51.

Anderson, L.W., Anderson, D.S., 1981. Weathering rinds on quartzarenite clasts as a relative-age indicator and the glacial chronology of Mount Timpanogos, Wasatch Range, Utah. Arctic and Alpine Research 13, 25–31.

Atwood, W.W., 1909. Glaciation of the Uinta and Wasatch Mountains. U.S. Geological Survey Professional Paper 61.

Baer, J.L., Davis, R.L., George, S.E., 1982. Structure and stratigraphy of the Pavant Range, central Utah. In: Nielson, D.L. (Ed.), Overthrust Belt of Utah Salt Lake City, Utah. Utah Geological Association Publication 10, pp. 31–48.

Benson, L.V., 1999. Records of millenial-scale climate change from the Great Basin of the western United States. In: Clark, P.U., Webb, R.S., Keigwin, L.D. (Eds.), Mechanisms of Global Climate Change. American Geophysical Union Geophysical Monograph, Washington, DC, 112, pp. 203–225.

Benson, L.V., Burdett, J.W., Kashgarian, M., Lund, S.P., Phillips, F.M., Rye, R.O. (1996). Climatic and hydrologic oscillations in the Owens Lake basin and adjacent Sierra Nevada, California, Science 274, pp. 746–749.

Benson, L.V., May, H.M., Antweiler, R.C., Brinton, T.L., Kashgarian, M., Smoot, J.P., Lund, S.P., 1998. Continuous lake sediment records of glaciation in the Sierra Nevada between 52,600 and 12,500 ^{14}C yr B.P. Quaternary Research 50, 113–127.

Bentley, E.B., 1970. The glacial geomorphology of Steens Mountain, Oregon. Unpublished Masters Thesis, University of Oregon.

Bentley, E.B., 1974. The glacial morphology of eastern Oregon uplands. Unpublished Ph.D. Thesis, University of Oregon.

Bevis, K.A., 1995. Reconstruction of late Pleistocene paleoclimatic characteristics in the Great Basin and adjacent areas. Unpublished Ph.D. Thesis, Oregon State University.

Bick, K.F., 1958. Geologic map and sections of the Deep Creek Quadrangle, Utah. Unpublished Ph.D. Thesis, Yale University.

Billingsley, G.H., Huntoon, P.W., Breed, W.J., 1987. Geologic map of Capitol Reef National Park and vicinity, Emery, Garfield, Millard and Wayne Counties, Utah. Utah Geological and Mineral Survey Map 87.

Blackwelder, E., 1931. Pleistocene glaciation in the Sierra Nevada and Basin Ranges. Geological Society of America Bulletin 42, 865–922.

Blackwelder, E., 1934. Supplementary notes on Pleistocene glaciation in the Great Basin. Washington Academy of Science Journal 24, 217–222.

Boden, D.R., 1992. Geologic map of the Toquima Caldera Complex, central Nevada. Nevada Bureau of Mines and Geology, Map 98, Scale 1 : 48,000.

Bradley, W.H., 1936. Geomorphology of the north flank of the Uinta Mountains. U. S. Geological Survey Professional Paper 185-I, 204 pp.

Brown, C.E., Thayer, T.P., 1966. Geologic map of the Canyon City Quadrangle, northeastern Oregon. U.S. Geological Survey Miscellaneous Investigations Map I–447, scale 1 : 250,000.

Callaghan, E., Parker, R.L., 1961. Geology of the Monroe Quadrangle, Utah. U.S. Geological Survey Geologic Quadrangle Map GQ–155, scale 1 : 62,500.

Cebull, S.E., 1970. Bedrock geology and orogenic succession in Southern Grant Range, Nye County, Nevada. The American Association of Petroleum Geologists Bulletin 54, 1828–1842.

Clark, D.H., 1995. Extent, timing, and climatic significance of latest Pleistocene and Holocene Glaciation in the Sierra Nevada, California. Unpublished Ph.D. Thesis, University of Washington.

Clark, D.H., Clark, M.M., 1995. New evidence of Late-Wisconsin deglaciation in the Sierra Nevada, California, refutes the Hilgard Glaciation. Geological Society of America, Abstracts with Programs 27, p. 10.

Clark, D.H., Gillespie, A.R., 1997. Timing and significance of Late-glacial and Holocene cirque glaciation in the Sierra Nevada, California. Quaternary International 38/39, 21–38.

Coats, R.R., 1964. Geology of the Jarbidge Quadrangle, Nevada, Idaho. U.S. Geological Survey Bulletin, M1–M24.

Crandell, D.R., 1965. The glacial history of western Washington and Oregon. In: Wright Jr., H.E., Frey, D.G. (Eds.), The Quaternary of the United States. Princeton University Press, Princeton, pp. 341–353.

Cunningham, C.G., Steven, T.H., Rowley, P.D., Glassgold, L.B., Anderson, J.J., 1983. Geologic map of the Tushar Mountains and adjoining areas, Marysvale Volcanic Field, Utah. U.S. Geological Survey Map I-1430A.

Currey, D.R., 1969. Neoglaciation in the mountains of the southwestern United States. Unpublished Ph.D. Thesis, University of Kansas.

Currey, D.R., Mulvey, W.D., 1986. Markagunt Plateau, Utah: southern margin of Late Wisconsinan montane glaciation in the Great Basin. Program and Abstracts of the Ninth Biennial Meeting, 2–4 June. American Quaternary Association, pp. 126.

Davis, P.T., Osborn, G., 1987. Age of pre-neoglacial cirque moraines in the central North American Cordillera. Geographie physique et Quaternaire 41 (3), 365–375.

Dohrenwend, J.C., 1984. Nivation landforms in the western Great Basin and their paleoclimatic significance. Quaternary Research 22, 312–324.

Dorn, R.I., 1996. Uncertainties in the radiocarbon dating of organics associated with rock varnish: a plea for caution. Physical Geography 17, 585–591.

Drewes, H., 1958. Structural geology of the southern Snake Range, Nevada. Geological Society of America Bulletin 69, 221–240.

Duffield, W.A., Weldin, R.D., 1976. Mineral resources of the south Warner wilderness, Modoc County, California. U.S. Geological Survey Bulletin 1385-D, 31.

Dutton, C.E., 1880. Report on the geology of the High Plateaus of Utah. Department of the Interior, U.S. Geographical and Geological Survey of the Rocky Mountain Region.

Elliot-Fisk, D.L., 1987. Glacial geomorphology of the White Mountains, California and Nevada: establishment of glacial chronology. Physical Geography 8, 299–323.

Ferguson, H.G., 1924. Geology and ore deposits of the Manhattan District, Nevada. U.S. Geological Survey Bulletin 723, 163.

Flint, R.F., 1947. Glacial Geology and Pleistocene Epoch. Wiley, New York, p. 589.

Flint, R.F., Denny, C.S., 1958. Quaternary geology of Boulder Mountain Aquarius Plateau, Utah. Contributions to General Geology, U.S. Geological Survey Bulletin 1061-D. 103–164.

Fullerton, D.S. 1986. Chronology and correlation of glacial deposits in the Sierra Nevada, California. In: Sibrava, V., Bowen, D.Q., Richmond, G.M. (Eds.), Quaternary Glaciations in the Northern Hemisphere. Report of the International Geological Correlation Programme Project 24, Pergamon Press, Oxford, pp. 161–169.

Gallie III, T.M., 1977. Aspects of the glacial environments of a late Pleistocene ice maximum in Little Cottonwood Canyon, Utah. Unpublished M.S. Thesis, University of Utah.

Gans, P.B., Miller, E.L., Clark, D.H., Rodgers, D.W., 1990. Geologic relations in the Kern Mountains-Deep Creek Range, Nevada-Utah and the origin of metamorphic core complex detachment faults. Geological Society of America, Abstracts With Programs 22 (3), 24.

Gilbert, G.K., 1875. Geology: U.S. Geog. and Geol. Surveys West of the 100th Meridian (Wheeler, G.M.), Vol. 3, 681 p.

Gilbert, G.K., 1890. Lake Bonneville. U.S. Geological Survey Monograph 1, 438.

Gillespie, A.R., Clark, M.M., Burke, R.M., 1999. Eliot Blackwelder and the alpine glaciations of the Sierra Nevada. In: Moores, E.M., Sloan, D., Stout, D.L. (Eds.), Classic Cordilleran Concepts: A View from California. Geological Society of America Special Paper 338, Boulder, Colorado pp. 443–452.

Gillespie, A.R., Molnar, P., 1995. Asynchronous maximum advances of mountain and continental glaciers. Reviews of Geophysics 33, 311–364.

Gould, L.M., 1939. Glacial geology of Boulder Mountain, Utah. Bulletin of the Geological Society of America 50, 1371–1380.

Grayson, D.K., 1993. The Desert's Past, a Natural Prehistory of the Great Basin. Smithsonian Institution Press, Washington, DC, 356 p.

Gregory, H.E., 1950. Geology of eastern Iron County, Utah. Utah Geological and Mineralogical Survey, Bulletin 37, 153.

Griggs Jr., J. (undated). Waite [sic] a Minute! A critical review of the Great Basin National Park proposal. Unpublished manuscript.

Halsey, J.H., 1953. Geology of parts of the Bridgeport, California and Wellington, Nevada quadrangles. Unpublished Ph.D. Thesis, University of California, Berkeley.

Harden, J.W., 1982. A quantitative index of soil development from field descriptions: examples from a chronosequence in central California. Geoderma 28, 1–28.

Harden, J.W., Taylor, E.M., 1983. A quantitative comparison of soil development in four climatic regimes. Quaternary Research 20, 342–359.

Harden, J.W., Taylor, E.M., Hill, C., Mark, R.K., McFadden, L.D., Reheis, M.C., Sowers, J.M., Wells, S.G., 1991. Rates of soil development from four soil chronosequences in the southern Great Basin. Quaternary Research 35, 383–399.

Hardy, C.T., Muessig, S., 1952. Glaciation and drainage changes in the Fish Lake Plateau, Utah. Bulletin of the Geological Society of America 63, 1109–1116.

Harrington, C.D., Whitney, J.W., Dorn, R.I., Bierman, P.R., Gillespie, A.R., 1995. Evidence suggesting that methods of rock-varnish cation-ratio dating are neither comparable nor consistently reliable; discussions and reply. Quaternary Research 43, 268–276.

Hart, S.L., 1978. Late Quaternary glacial events in the Big Cottonwood drainage area, Wasatch Mountains, Utah. Unpublished M.S. Thesis, University of Utah.

Hatfield, S.C., Rowley, P.D., Sable, E.G., Maxwell, D.J., Cox, B.V., McKell, M.D., Kiel, D.E., 2000b. Geology of Cedar Breaks National Monument, Utah. In: Sprinkel, D.A., Chidsey Jr., T.C., Anderson, P.B. (Eds.), Geology of Utah's Parks and Monuments. Utah Geological Association Publication 28, Salt Lake City, Utah, pp. 139–154.

Hatfield, S.C., Rowley, P.D., Anderson, J.J., 2000a. Cedar Breaks National Monument, Utah: giant gravity slides complicate an otherwise simple story. Geological Society of America Abstracts with Programs 32, A-263.

Heald, W., 1956. An active glacier in Nevada. American Alpine Journal 9, 164–167.

Hose, R.K., Blake Jr., M.C., 1976. Geology and mineral resources of White Pine County, Nevada-part 1: Geology. Nevada Bureau of Mines and Geology Bulletin 85, 1–35.

Houghton, J.G., 1969. Characteristics of rainfall in the Great Basin. Desert Research Institute, Reno, Nevada, 205 p.

Howard, K.A., Kistler, R.W., Snoke, A.W., Willden, R., 1979. Geological map of the Ruby Mountains, Nevada. U.S. Geological Survey, Miscellaneous Investigations Series, Map I-1136.

Hulbe, C.W., 1980. Geology of the Warner Mountains. In: Curtis, K.J. (Ed.), Geologic Guide to the Modoc Plateau and the Warner Mountains. Geological Society of Sacramento, Sacramento, California, pp. 149–156.

Hunt, C.B., 1956. Cenozoic geology of the Colorado Plateau. U. S. Geological Survey Professional Paper 279, 99 p.

Ives, R.L., 1946. Glaciation in the Desert Ranges, Utah. Journal of Geology 54, 335.

Ives, R.L., 1950. Glaciations in Little Cottonwood Canyon, Utah. The Scientific Monthly August, 105–117.

Kelsey, M.R., 1989. Climbing and Exploring Utah's Mt. Timpanogos. Kelsey, Publishing, Provo, Utah, 208 p.

Kinney, D.M., 1955. Geology of the Uinta River — Brush Creek area, Duchesne and Uinta Counties, Utah. U. S. Geological Survey Bulletin 1007, 185 p.

Kleinhampl, Ziony, 1985. Geology of northern Nye County, Nevada. Nevada Bureau of Mines and Geology Bulletin B99A, 172 p.

Kramer, F.L., 1962. Rivers of stone. Pacific Discovery 15 (5), 11–15.

Laidley, R.A., McKay, D.S., 1971. Geochemical examination of obsidians from Newberry Caldera. Contributions to Mineralogy and Petrology 30, 336–342.

Langer, V.W., 1992. Geology and petrolocic evolution of the silicic to intermediate volcanic rocks underneath Steens Mountain basalt, SE Oregon. Unpublished Masters Thesis, Oregon State University.

LaMarche Jr., V.C., 1965. Distribution of Pleistocene glaciers in the White Mountains of California and Nevada. U. S. Geological Survey, Professional Paper 525-C, pp. C146–C147.

Lawrence, E., 1958. The Wheeler Glacieret of the Wheeler Peak area, White Pine County, Nevada. Unpublished manuscript, Nevada Bureau of Mines, Reno.

Lumsden, Jr., W.W., 1964. Geology of the southern White Pine Range and northern Horse Range, Nye and White Pine Counties, Nevada. Unpublished Ph.D. Thesis, California University, Los Angeles.

Lund, E.H., Bentley, E., 1976. Steens Mountain, Oregon. The Ore Bin 38 (4), 51–56.

MacLeod, N.S., Sherrod, D.R., Chitwood, L.A., Jensen, R.A., 1995. Geologic map of Newberry Volcano, Deschutes, Klamath, and Lake Counties, Oregon. U.S. Geological Survey Miscellaneous Investigations Series, Map I–2455, scale 1 : 62,500 and 1 : 24,000.

MacLeod, N.S., Sherrod, D.R., Chitwood, L.A., McKee, E.H., 1981. Newberry Volcano, Oregon. In: Johnson, D.A., Donnelly-Nolan, J. (Eds.), Guides to Some Volcanic Terranes in Washington, Idaho, Oregon, and Northern California. Geological Survey Circular 838, pp. 85–91.

Madsen, D.B., Currey, D.R., 1979. Late Quaternary glacial and vegetation changes, Little Cottonwood Canyon area, Wasatch Mountains, Utah. Quaternary Research 12, 254–270.

Madsen, D.B., O'Connell, J.F., 1982. Man and Environment in the Great Basin. Society for American Archeology Papers No. 2, 242 p.

Marchetti, D.W., Cerling, T.E., 2000. Cosmogenic dating. In: Waitt, R.B., Marchetti, D.W., Cerling, T.E., Kreutzer, L., Anderson, A. (Eds.), Red Gate to Blue Gate, Field Guide to Friends of the Pleistocene Rocky Mountain Section 44th Annual Meeting, 26 p.

Martin Jr., R.A., Nelson, A.R., Weisser, R.R., Sullivan, J.T., 1985. Seismotectonic study for Taskeetch dam and reservoir site, Upalco unit, and upper Stillwater dam and reservoir site, Bonneville unit, central Utah project, Utah (unpublished report). U.S. Bureau of Reclamation, Engineering and Research Center Seismotectonic Section Report 85-2, 191 p.

McCoy, W.D., 1977. A reinterpretation of certain aspects of the late Quaternary glacial history of Little Cottonwood Canyon, Wasatch Mountain, Utah. Unpublished M.A. Thesis, University of Utah.

McKee, E.H., Diggles, M.F., Donahoe, J.L., Elliot, G.S., 1982. Geologic map of the White Mountains wilderness and roadless areas, California and Nevada. U.S. Geological Survey, Miscellaneous Field Studies Map MF136A.

Meinzer, O.E., 1917. Geology and water resources of Big Smoky, Clayton and Alkali Spring Valleys, Nevada. U. S. Geological Survey Water Supply Paper 423, 167 p.

Mehringer, P.J., Nash, W.P., Fuller, R.H., 1971. A Holocene volcanic ash from northwestern Utah. Utah Academy Proceedings 48, 46–51.

Menounos, B., Reasoner, M.A., 1997. Evidence for cirque glaciation in the Colorado Front Range during the Younger Dryas Chronozone. Quaternary Research 48, 38–47.

Mifflin, M.D., Wheat, M.M., 1979. Pluvial lakes and estimated pluvial climates of Nevada. Nevada Bureau of Mines and Geology, Bulletin 94, 5–50.

Miller, E.L., Grier, S.P., 1993. Geologic Map of Lehman Caves Quadrangle, White Pine County, Nevada. U.S. Department of the Interior and U.S. Geological Survey, Open-file Report 93–209.

Mitchell, V.L., 1976. The regionalization of climate in the western United States. Journal of Applied Meteorology 15, 920–927.

Moore, D.W., Nealey, L.D., 1993. Preliminary geologic map of Navajo Lake Quadrangle, Kane and Iron Counties, Utah. U.S. Geological Survey Open File Report 93–190, 20 p.

Moores, E.M., Scott, R.B., Lumsden, W.W., 1968. Tertiary tectonics of the White Pine-Grant Range region, east central Nevada, and some regional implications. Geological Society of America Bulletin 79, 1703–1726.

Mulvey, W.E., Currey, D.R., Lindsay, L.M.W., 1984. Southernmost occurrence of later Pleistocene glaciation in Utah: Brian Head-Signey Peaks area, Markagunt Plateau. Encyclopedia 61, 97–101.

Osborn, G., 1973. Quaternary geology and geomorphology of the Uinta Basin and the south flank of the Uinta Mountains, Utah. Ph.D. thesis, University of California, Berkeley, 266 p.

Osborn, G., 1989. Glacial deposits and tephra in the Toiyabe Range, Nevada, U.S.A. Arctic and Alpine Research 21 (3), 256–267.

Osborn, G., 1990. The Wheeler Peak cirque and glacier/rock glacier. Unpublished report prepared for the Great Basin Natural History Association. University of Calgary Dept. of Geology and Geophysics.

Osborn, G., Gerloff, L., 1997. Latest Pleistocene and early Holocene fluctuatons of glaciers in the Canadian and northern American Rockies. Quaternary International 38/39, 7–19.

Osborn, G., Luckman, B.H., 1988. Holocene glacier fluctuations in the Canadian Cordillera (Alberta and British Columbia). Quaternary Science Reviews 7, 115–128.

Oviatt, C.G., 1992. Quaternary geology of the Scipio Valley area, Millard and Juab Counties, Utah. Utah Geological Survey, Special Study 79.

Oviatt, C.G., 1994. Quaternary Geologic Map of the Upper Weber River Drainage Basin, Summit County, Utah. Utah Geological Survey Map 156.

Oviatt, C.G., McCoy, W.D., 1992. Early Wisconsin lakes and glaciers in the Great Basin, U.S.A. Geological Society of America Special Paper 270, pp. 279–287.

Phillips, F.M., Zreda, M.G., Benson, L.V., Plummer, M.A., Elmore, D., Sharma, P., 1996. Chronology for fluctuations in late Pleistocene Sierra Nevada glaciers and lakes. Science 274, 749–751.

Piegat, J.J., 1980. Glacial geology of central Nevada. Unpublished M.S. Thesis, Purdue University.

Porter, S.C., Pierce, K.L., Hamilton, T.D., 1983. Late Wisconsin mountain glaciation in the western United States. In: Porter, S.C. (Ed.), Late Quaternary Environments of the United States, Vol. 1, The Late Pleistocene. University of Minnesota Press, Minneapolis, pp. 71–111.

Reasoner, M.A., Osborn, G., Rutter, N.W., 1994. Age of the Crowfoot Advance in the Canadian Rocky Mountains: a glacial event coeval with the Younger Dryas Oscillation. Geology 22, 439–442.

Reheis, M.C., 1994. Comments on "Soil development parameters in the absence of a chronosequence in a glaciated basin of the White Mountains, California-Nevada" by T.W. Swanson, D.L. Elliott-Fisk, and R.J. Southard. Quaternary Research 41, 245–249.

Reneau, S.L., Oberlander, T.M., Harrington, C.D., 1991. Accelerator mass spectrometry radiocarbon dating of rock varnish: discussion. Geological Society of America Bulletin 103 (2), 310–311.

Rennie, D.P., 1987. Late Pleistocene alpine glacial deposits in the Pine Forest Range, Nevada. Unpublished Masters Thesis, University of Nevada, Reno.

Richmond, G.M., 1964. Glaciation of Little Cottonwood and Bells Canyons, Wasatch Mountains, Utah. Shorter Contributions to General Geology, pp. D1–D41.

Richmond, G.M., 1986. Stratigraphy and correlation of glacial deposits of the Rocky Mountains, the Colorado Plateau and the Ranges of the Great Basin. In: Sibrava, V., Bowen, D.Q., Richmond, G.M. (Eds.), Quaternary Glaciations in the Northern Hemisphere. Report of the International Geological Correlation Programme Project 24, pp. 99–128.

Rigby, J.K., 1958. Geology of the Stansbury Mountains, eastern Tooele County, Utah. In: Rigby, J.K. (Ed), Guidebook to the Geology of Utah, Vol. 13. Utah Geological Society, Salt Lake City, Utah, pp. 1–133.

Robinson, J.P., 1987. Late Cenozoic high- and low-angle normal faulting and related igneous events in Gold Hill, northern Deep Creek Mountains, western Utah. Utah Geological Association Publication 16, 429–436.

Rowley, P.D., Steven, T.A., Anderson, J.J., Cunningham, C.G., 1979. Cenozoic stratigraphic and structural framework of southwestern Utah. U.S. Geological Survey Professional Paper 1149.

Russell, I.C., 1885. Geological history of Lake Lahontan, a Quaternary lake of northwestern Nevada. U. S. Geological Survey Monograph 11, 288.

Russell, I.C., 1903. Notes on the geology of southwestern Idaho and southeastern Oregon. U. S. Geological Survey Bulletin 217, 83.

Russell, I.C., 1905. Geology and water resources of central Oregon. U. S. Geological Survey Bulletin 252, 1–138.

Sarna-Wojcicki, A., Champion, D., Davis, J., 1983. Holocene volcanism in the conterminous United States and the role of silicic volcanic ash layers in correlation of latest-Pleistocene and Holocene deposits. In: Wright Jr., H. (Ed.), Late Quaternary Environments of the United States 2. University of Minnesota Press, Mineapolis, pp. 52–77.

Scott, W.E., 1988. Temporal relations of lacustrine and glacial events at Little Cottonwood and Bells Canyons, Utah. Utah Geological and Mineral Survey, Miscellaneous Publication 88-1, 78–81.

Sharp, R.P., 1938. Pleistocene Glaciation in the Ruby-East Humboldt Range, northeastern Nevada. Journal of Geomorphology 1, 296–323.

Smith, W.D., 1927. Contribution to the geology of southeastern Oregon: Steens and Pueblo Mountains. Journal of Geology 35, 421–440.

Smith, J.G., 1973. Geologic map of the Duffer Peak Quadrangle, Humboldt county, Nevada. U.S. Geological Survey, Miscellaneous Geologic Investigations Map I-606, Scale 1 : 48,000.

Smith, J.F., Huff, L.C., Hinrichs, E.N., Luedke, R.G., 1963. Geology of the Capital Reef area, Wayne and Garfield counties, Utah. U. S. Geological Survey Professional Paper 363, 102 p.

Sorensen, M.L., 1982. Geologic map of the Stansbury roadless areas, Tooele county, Utah. U.S. Geological Survey, Miscellaneous Field Studies Map MF-1353-A.

Spieker, E.M., Billings, M.P., 1940. Glaciaiton in the Wasatch Plateau, Utah. Bulletin of the Geological Society of America 51, 1173–1198.

Steven, T.A., Cunningham, C.G., Nasser, C.W., Mehnert, H.H., 1979. Revised stratigraphy and radiometric ages of volcanic rocks and mineral deposits in the Marysville area, west-central Utah. U. S. Geological Survey Bulletin 1469, 40.

Stewart, J.H., 1980. Geology of Nevada. Nevada Bureau of Mines and Geology Special Publication 4, 136 p.

Stewart, J.H., McKee, E.H., 1977. Geology and Mineral Deposits of Lander Co., NV. Part I: Geology. Nevada Bureau of Mines and Geology Bulletin 88, 106.

Swanson, T.W., Elliot-Fisk, D.L., Southard, R.J., 1993. Soil development parameters in the absence of a chronosequence in a glaciated basin of the White Mountains, California-Nevada. Quaternary Research 39, 186–200.

Thayer, T.P., 1956. Preliminary geologic map of the John Day Quadrangle, Oregon. U.S. Geological Survey Mineral Inv. Field Studies Map MF 51, scale 1 : 62,500.

Thompson, R.S., Mead, J.I., 1982. Late Quaternary environments and biogeography in the Great Basin. Quaternary Research 17, 39–55.

Tooker, E.W., Roberts, R.J., 1971. Structures related to thrust faults in the Stansbury Mountains, Utah. U.S. Geological Society Professional Paper pp. B1–B12.

Tucker, L., 1954. Geologic map of the Scipio Quadrangle, Utah. Unpublished Ph.D. Thesis, Ohio State University, Colombus.

van Hoesen, J.G., Orndorff, R.L., Saines, M., 2000. Evidence for Pleistocene glaciation in the Spring Mountains, Nevada. Geological Society of America Abstracts with Programs 32, A16.

Vikre, P.G., 1985. Geologic map of the Buckskin Mountain Quadrangle, Nevada. Nevada Bureau of Mines and Geology Map 88, scale 1 : 24,000.

Waite, R., 1974. The proposed Great Basin National Park: A geographical interpretation of the southern Snake Range, Nevada. Unpublished Ph.D. Thesis, University of California at Los Angeles Geography Dept.

Waitt, R.B., 2000. Road Log. In: Waitt, R.B., Marchetti, D.W., Cerling, T.E., Kreutzer, L., Anderson, A. (Eds.), Red Gate to Blue Gate, Field Guide to Friends of the Pleistocene Rocky Mountain Section 44th Annual Meeting, pp. 25–26.

Walker, G.W., 1990. Miocene and younger rocks of the Blue Mountains region, exclusive of the Columbia River basalt group associated mafic lava flows. In: Walker, G.W. (Ed.), Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Cenozoic Geology of the Blue Mountains Region. U.S. Geological Survey Professional Paper 1437, pp. 101–118.

Walker, G.W., Robinson, P.T., 1990. Paleocene(?), Eocene, and Oligocene(?) rocks of the Blue Mountain region. In: Walker, G.W. (Ed.), Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: Cenozoic Geology of the Blue Mountains Region. U.S. Geological Survey Professional Paper 1437, pp. 13–27.

Wayne, J.W., 1983. Paleoclimatic inferences from relict cryogenic features in alpine regions. Permafrost: Fourth International Conference, Proceedings, pp. 1378–1383.

Wayne, J.W., 1984. Glacial chronology of the Ruby Mountains — East Humboldt Range, Nevada. Quaternary Research 21, 286–303.

Wilkerson, W.L., 1958. The geology of a portion of the southern Steens Mountains, Oregon. Unpublished Masters Thesis, University of Oregon.

Winograd, I.J., Landwehr, J.M., Ludwig, K.R., Coplen, T.B., Riggs, A.C., 1997. Duration and structure of the past four interglaciations. Quaternary Research 48, 141–154.

Zielinski, G.A., McCoy, W.D., 1987. Paleoclimatic implications of the relationship between modern snowpack and late Pleistocene equilibrium-line altitudes in the mountains of the Great Basin, western U.S.A. Arctic and Alpine Research 19 (2), 127–134.

Zreda, M.G., Phillips, F.M., 1995. Insights into alpine moraine development from cosmogenic ^{36}Cl buildup dating. Geomorphology 14, 149–156.