USGS-OFR-96-514

U. S. DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

OLD, VERY HIGH PLUVIAL LAKE LEVELS IN THE LAHONTAN BASIN, NEVADA: EVIDENCE FROM THE WALKER LAKE BASIN

Contributions to the Guidebook, 1996 Field Trip, Pacific Cell, Friends of the Pleistocene

by

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Open-File Report 96-514

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards (or with the North American Stratigraphic Code)

1996

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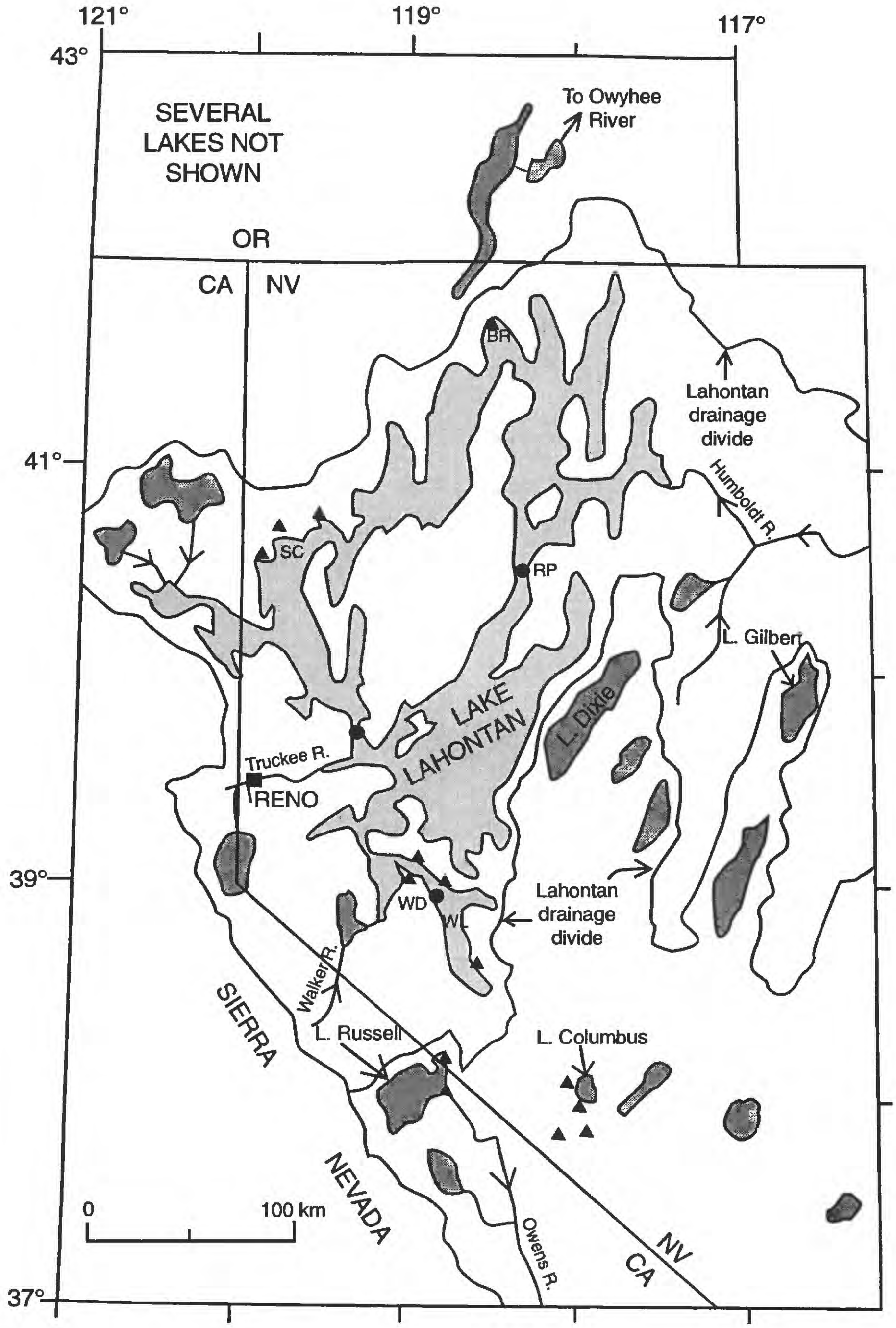


Figure 1. Regional map showing Lahontan basin and late Pleistocene areas of Lake Lahontan (light shading) and other pluvial lakes (dark shading). Dots, previously known sites of pre-late Pleistocene lacustrine sediment; triangles, locations from this study. BR, Black Rock Desert; SC, Smoke Creek Desert; RP, Rye Patch Dam; WD, Weber Dam; WL, Walker Lake.

Introduction

During highstands of the late middle and late Pleistocene, pluvial Lake Lahontan covered more than 21,000 km^2 and extended more than 350 km from northern Nevada to near the southern end of Walker Lake (fig. 1). Deposits and elevations of shorelines of this age have been studied for over a century (e.g. Russell, 1885; Morrison, 1991). However, relatively little information was available on older deposits, and shorelines of older lakes in the Lahontan basin reported in the present paper have not been previously identified. In 1995, new mapping was undertaken to investigate possible older extensions of Lake Lahontan to the south of Walker Lake and to investigate Mifflin's (1984) hypothesis of long-term northward tilting of northwestern Nevada. Astonishingly abundant sedimentologic and geomorphic evidence of

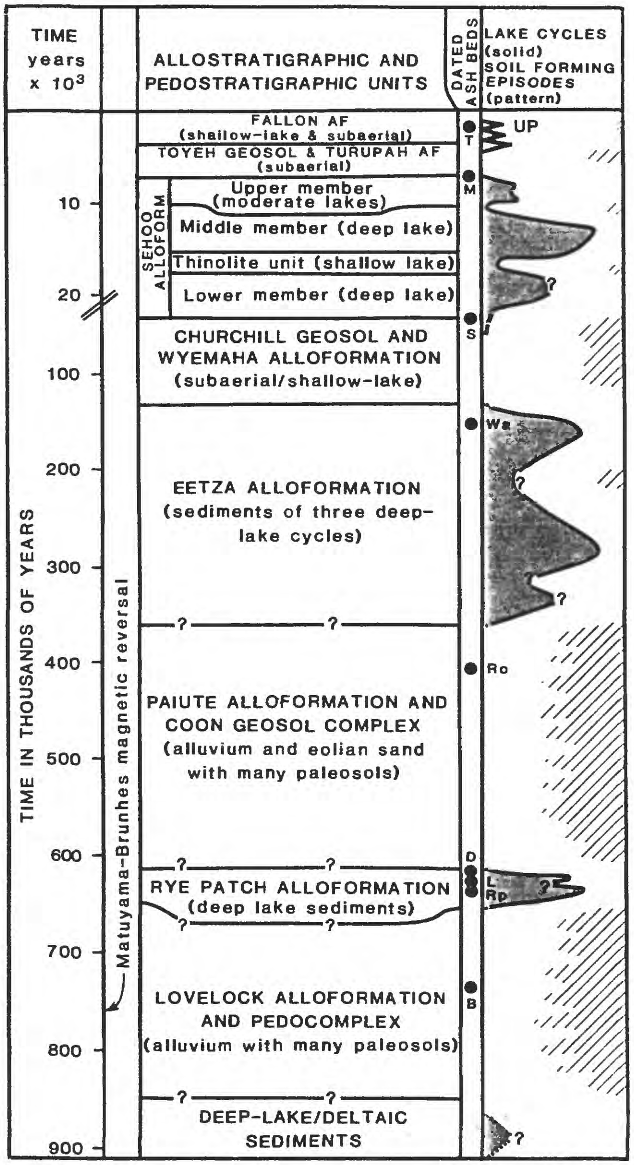


Figure 2. Principal exposed Quaternary units in the Lahontan basin, tephra layers, and inferred fluctuations in lake level (from Morrison, 1991). In the lake-level graph, solid indicates lacustrine episodes; hatching indicates soil-forming episodes. Letters in ash-bed column denote tephra layers of known age: T, Turupah Flat, 1.2 ka; M, Mazama, 6.8 ka; S, Mt. Saint Helens W-Marble Bluff, 35 ka; Wa, Wadsworth, ~150 ka; Ro, Rockland, 400 ka; D, Dibekulewe, 610 ka; L, Lava Creek B, 620 ka; Rp, Rye Patch Dam, 630 ka; B, Bishop 760 ka (see references in Morrison, 1991, for sources of tephra ages).

lakes much older, and shorelines much higher, than the late Pleistocene lakes in western Nevada (Lakes Lahontan, Columbus, and Russell) is preserved in many places. Shoreline elevations at sites in the Lahontan basin seem to indicate that northward tilting has not occurred, although the shorelines probably have been locally displaced as much as 20 m by faulting.

The purpose of this paper is to present preliminary information on the sedimentology, stratigraphy, and estimated shoreline elevations of pluvial lakes in the Lahontan basin prior to the late middle Pleistocene (the past ca. 200 ka, fig. 2). Discussion will focus on several sites in the Walker Lake basin which preserve abundant evidence of old lake cycles, in particular two areas (McGee Wash and Thorne Bar, fig. 3) which will be visited on the field trip. Similar thick sedimentary sequences have not yet been found in the main Lahontan basin north of the Desert Mountains; however, a few areas (triangles in fig. 1) exhibit beach pebbles or gravel at anomalously high elevations that correspond to shoreline elevations inferred from the Walker Lake area. Although previous workers have restricted the use of "Lake Lahontan" to the Eetza and Sehoo Formations of the Lahontan Valley Group, in this paper it is extended to all Pleistocene deep-lake deposits in the Lahontan basin.

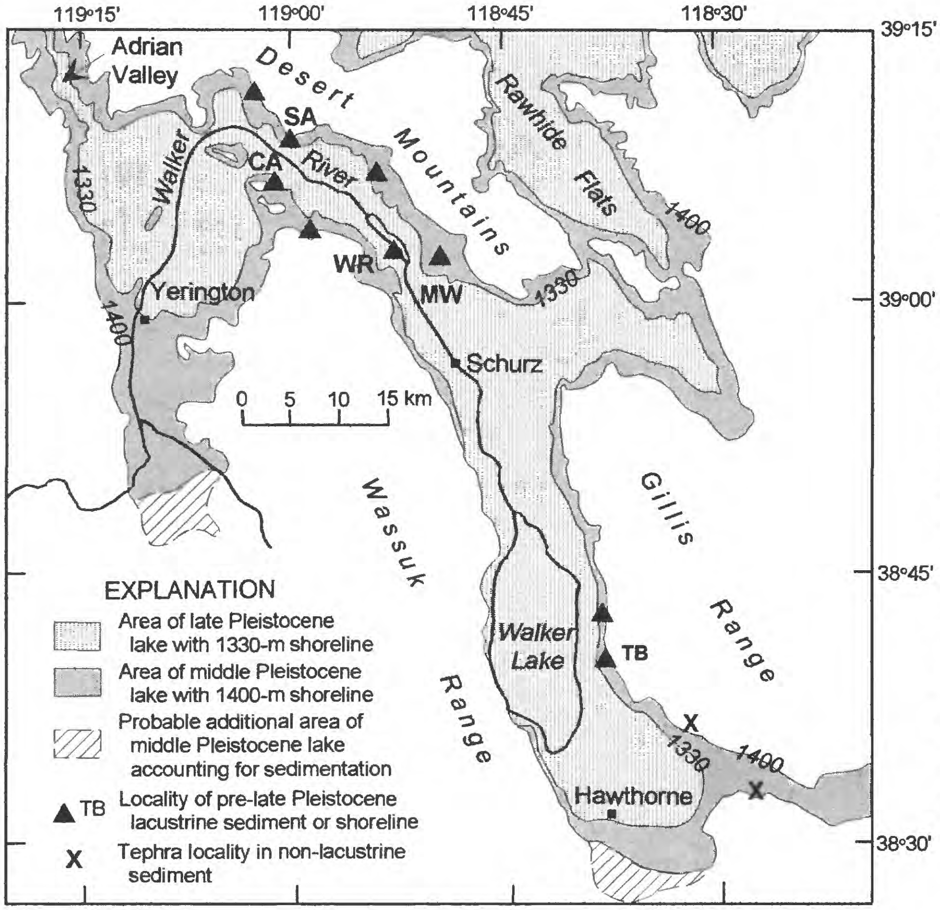


Figure 3. Map of Walker Lake basin and southernmost Carson Desert (Rawhide Flats) showing study sites and areas of lake at different times. Area of lake at 1400 m is drawn using modern topography, recognizing this is an approximation of topography in the middle Pleistocene due to faulting, erosion, and sedimentation. SA, Sunshine Amphitheater; CA, Campbell Amphitheater; WR, Weber Reservoir; MW, McGee Wash; TB, Thorne Bar.

Acknowledgments

This project was initially conceived and funded as a Gilbert Fellowship by the U.S. Geological Survey, and I thank my co-proposer and behind-the-scenes director, Marty Mifflin, for all his inspiration and vast store of Lahontan knowledge. Roger Morrison reviewed early versions of the proposal and kindly introduced me to several areas where pre-late Pleistocene Lahontan deposits were known. Ken Adams occasionally raised his eyes above the Sehoo and Eetza levels to observe and feed me interesting sites to study; it's been a great pleasure bouncing hypotheses off him. Jim Honey, Chuck Repenning, and Bob Miller kindly identified vertebrate fossils and Platt Bradbury identified diatom samples. Rich Reynolds and Joe Rosenbaum provided laboratory facilities, taught me how to analyze paleomagnetic samples, and advised on interpretation; Becky Gagliardi helped with analyses. Andrei Sarna-Wojcicki and Charlie Meyer, in the face of great obstacles and turmoil in the U.S.G.S., have again worked miracles to provide a chronological framework from numerous tephra samples—what would we do without you? Finally, I thank my volunteer field assistants, who worked very hard in a lot of bad weather and put up with my camping habits: Andrea Lonner, Nadine Calis, and Cassie Fenton.

Previous Work

Mifflin and Wheat (1979) and Benson (1978) observed that the Eetza (ca. 180-130 ka, but possibly as old as 300 ka; Morrison, 1991) and Sehoo (ca. 35-12 ka; Benson et al., 1990) shorelines in unfaulted positions throughout the Lahontan basin lie at about 1330 m. Isostatic rebound has caused shoreline elevations to range from about 1318 m at the northeastern margin of the lake to as much as 1343 m in the Carson Desert (Mifflin, 1984). The highest faulting rates of late Pleistocene shorelines are along the Wassuk fault, which bounds the west side of the Walker Lake basin (fig. 3). Leveling surveys by Demsey (1987) showed that elevations of the Sehoo shoreline along the Wassuk Range front range from 1325 m to 1333 m. She found no evidence of Quaternary faulting or deformation along the Gillis Range east of Walker Lake, where the average altitude of the Sehoo shoreline is 1329.5 ± 0.9 m.

Morrison (1991) summarized the known ages and elevations of early middle (ca. 780-610 ka; Richmond and Fullerton, 1986) and early Pleistocene (>780 ka) deposits of Lake Lahontan (fig. 2). Five sites were in outcrops below the Sehoo shoreline where incision exposed older deposits buried by Sehoo and Eetza sediment. The sixth site, Thorne Bar, is described below. Of the five, the Wyemaha Valley locality has been destroyed by gravel-pit operations, and lateral erosion by the Truckee River below Wadsworth has revealed the old deltaic gravel at the base of the canyon to be a fallen block of much younger gravel (field observations of the author). The two pre-Eetza lake cycles identified by Morrison (1991) are the Rye Patch Formation, about 630-610 ka, and unnamed deposits containing ~1,000-ka Glass Mountain tephra. He believed that the 760-ka Bishop ash bed was deposited during a long period of non-lacustrine sedimentation (the Lovelock Formation) with no deep lakes in the Lahontan basin. However, the Bishop ash bed is contained within or near the top of lacustrine deposits in basins to the south, including pluvial lakes Rennie (Fish Lake Valley; Reheis et al., 1993), Owens (Smith et al., 1993), Tecopa (Sarna-Wojcicki et al., 1987), and Manley (Death Valley; Knott et al., 1996).

Only in the Walker Lake basin are there previously known outcrops of undisputed beach and shallow-water gravel at an elevation higher than the Sehoo and Eetza shorelines. W.J. McGee observed that the eastern end of the "crest of the gravel embankment separating Walker Lake Valley from the … Walker River… is now fully 200 feet above its original position…" [that is, the Sehoo shoreline] (Russell, 1885, p. 142 and plate 28). This locality appears to be the area at the head of a drainage informally named McGee Wash east of Weber Dam (fig. 3; field trip stop 4 of day 2). Curiously, it seems never to have been resurveyed until the present study. The Thorne Bar, at the southeast edge of Walker Lake (figs. 1 and 3) was first reported by King (1978) and Mifflin and Wheat (1979) to have pre-Eetza "shore gravel with layers of lake-deposited carbonate, preserved in a much-eroded V-bar complex…up to 1443 m altitude" (Morrison, 1991, p. 296). All of these authors attributed the anomalously high shore gravel to tectonics. At the McGee Wash site, Russell (1885) thought the gravels had been folded into an anticline; recent mapping (see fig. 5) and that of Morrison and Davis (1984) confirms the presence of numerous faults and tilted strata. The Thorne Bar was attributed either to faulting (King, 1978, p. 67-68) or to northward tilting of the entire Lahontan basin (Mifflin and Wheat, 1979; Mifflin, 1984; Morrison, 1991). However, this site is across the Walker Lake basin from the tectonically active Wassuk fault, and detailed leveling surveys by Demsey (1987, p. 39-40) and air-photo interpretation for the present study reveal no evidence of Quaternary faulting or deformation either at the Thorne Bar or northward along the Gillis Range.

Evidence for Old, Very High Pluvial Lake Levels

The evidence for high stands of pre-Eetza pluvial lakes and shoreline elevations is primarily sedimentologic. The classic shoreline morphologies, such as wave-cut cliffs and beach berms, are commonly not detectable after half a million years of geomorphic change, although two such berms and one dissected V-bar are preserved in the Walker Lake basin. The twofold basic approach was developed in combination with investigations of known (Thorne Bar) or suspected (Campbell and Sunshine Amphitheaters, first noticed by Ken Adams) sites: (1) comb geologic maps for areas shown as late Tertiary lacustrine units or well stratified deposits (bedrock mappers commonly assumed that all lacustrine deposits above the Sehoo shoreline must be Tertiary in age); and (2) based on the elevation of shore gravel at the Thorne Bar, search topographic maps for bench-and-riser morphology between 1330 and 1400 m.

Outcrops of pre-Eetza lacustrine sequences in the Walker Lake basin range from well bedded mudstone, siltstone, and sandstone to steeply dipping coarse gravel conglomerate. The highest elevation of pebble- or cobble-sized beach gravel is taken as a minimum shoreline elevation. Locally, well-rounded beach pebbles of various lithologies lie as scattered lag on bedrock outcrops and also yield minimum shoreline elevations. Fine-grained beds locally contain tephra layers; these are being identified by chemical correlation with known tephra by the U.S. Geological Survey Tephrochronology Laboratory in Menlo Park. Ages of the units are further constrained by magnetostratigraphy and by identification of vertebrate fossils (Jim Honey and Chuck Repenning, U.S. Geological Survey). This work is ongoing and ages given in this report are preliminary. A unified stratigraphic sequence for the Walker Lake area has not been constructed because unit ages are preliminary or unknown. Thus, units with the same names among the individual stratigraphic sequences may not be the same age (see fig. 8 below).

Walker Lake Basin

The Walker River drains the Sierra Nevada (fig. 1) and presently feeds Walker Lake; in the past, however, the river has sometimes drained north into the Carson Desert via Adrian Valley (fig. 3; King, 1993). The Walker Lake basin mainly trends north-south and is bounded on the west by the Wassuk Range and an active fault and on the east by the Gillis Range. At the north end of the Gillis Range, active right-lateral faults of the Walker Lane intersect the basin and cause a northwest shift in the trend of the basin (fig. 3). The Thorne Bar and a nearby site lie in a tectonically quiescent area of the basin (Demsey, 1987). Sites north of Schurz have been faulted and tilted.

Thorne Bar area

The Thorne Bar is a large V-shaped bar of shore gravel built at the mouth of a large canyon draining the Gillis Range (fig. 4). The bar consists mainly of pebble to cobble gravel, locally tufa-cemented, with bedding ranging from horizontal to angles of 25° or more. The bar can be divided into three morphologic units: the lowest in elevation and youngest is a sharp, well preserved V-bar marked at the top by the Sehoo shoreline at 1330 m (ca. 4360 feet, fig. 4). Between 1330 m and about 1370 m (4500 feet), the bar consists of two nested, eroded V-shaped berms; the lower berm is better preserved than the upper. Between about 1370 and 1402 m (4600 feet) the bar has no preserved morphology, but deep arroyos expose well bedded, tufa-cemented shore gravel, and beach pebbles locally occur as lag on basalt outcrops (fig. 4). No stratigraphic relations have been deciphered within these gravel deposits. However, the degree of morphologic preservation of the nested bars and reconnaissance soil pits strongly suggest the presence of at least four and probably more lacustrine units: the Sehoo-aged bar, two older bars

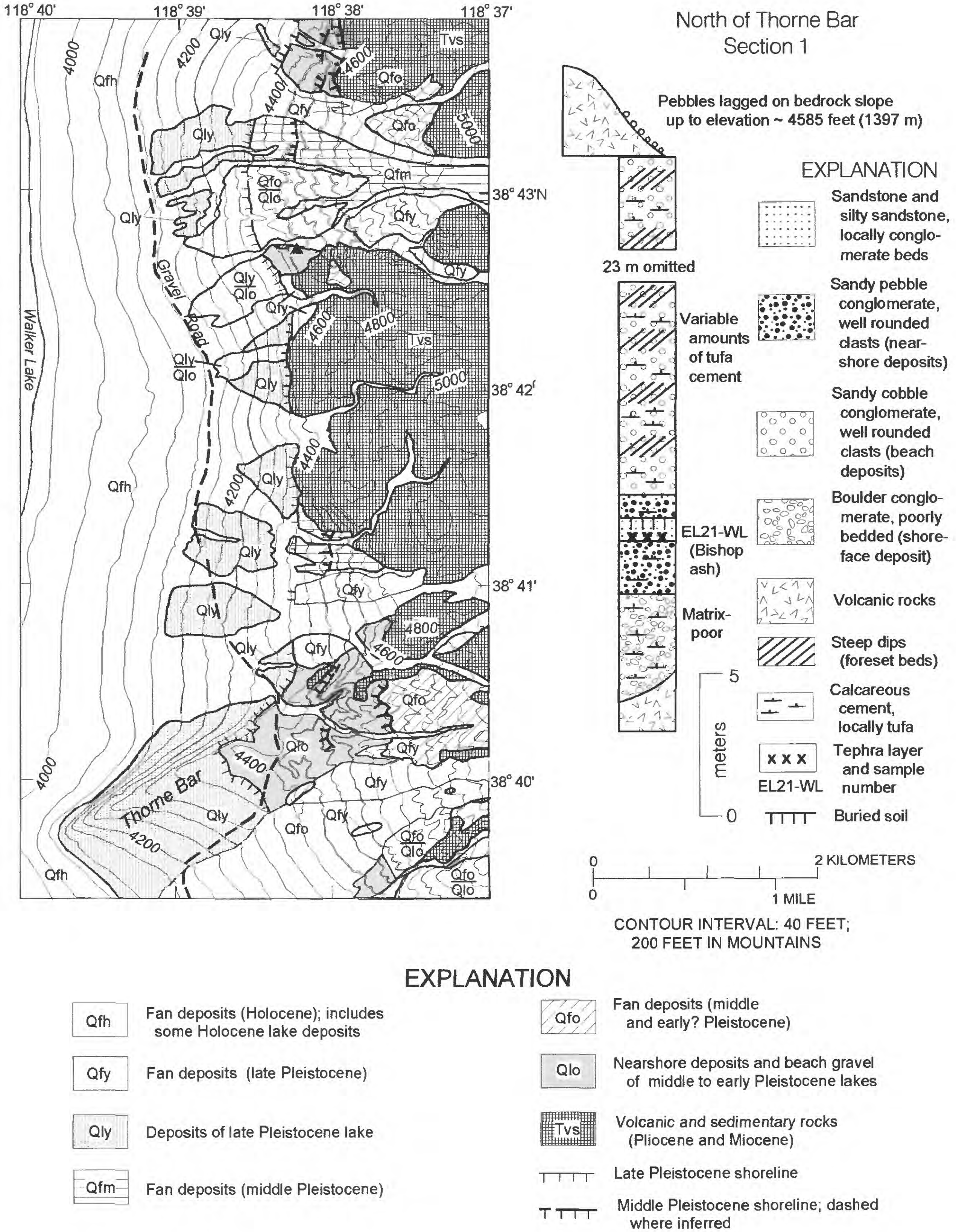


Figure 4. Map and measured section of area around Thorne Bar (see fig. 3 for location). Most contacts were mapped using air-photo interpretation. Triangle in northern map area is location of measured section.

that reached elevations between 1330 and 1370 m, and at least one old bar that reached a minimum elevation of 1402 m. King (1978) reported shore gravel as high as 1443 m; I found subrounded fan gravel but no obvious beach clasts above 1402 m.

An excellent small outcrop about 4 km north (measured section in fig. 4) of the Thorne Bar exposes two sequences of shore gravel, separated by a paleosol, that overlie bedrock; both sequences are well above the Sehoo shoreline. The lower unit, about 7 m thick, consists of a basal shoreface gravel that fines upward into silty sand containing tephra, in turn overlain by a pebbly poorly bedded stratum with a paleosol (Bt/Bk horizons). The tephra (EL-21-WL) is chemically correlative with the Bishop-Glass Mountain family of tephra erupted from Long Valley, California, and paleomagnetic measurements on the silty beds indicate normal polarity; thus this tephra is probably the 760-ka Bishop ash bed. The paleosol is abruptly overlain by about 38 m of tufa-cemented pebble and cobble shore gravel, commonly steeply bedded, that rises to an elevation of about 1393 m. Beach pebbles continue upward as lag on bedrock to an elevation of about 1395 m. Because the outcrops here and of the oldest unit at the Thorne Bar are similar in cementation and preservation and rise to about the same elevation, I infer that they are equivalent. Thus, the oldest and highest shoreline in this area is underlain by deposits of two different lakes: one that culminated at about the time of the eruption of the Bishop ash bed at 760 ka and reached a minimum elevation of about 1355 m, and a second that postdated the Bishop ash and rose to a minimum elevation of about 1400 m.

McGee Wash

The study site at McGee Wash extends from Weber Reservoir on the Walker River eastward to U.S. Highway 95 (figs. 3 and 5). The good outcrops in this area exhibit numerous faults and tilted sediments (Morrison and Davis, 1984); only a few of the larger faults are shown on figure 5. Dips are generally greatest in the east near the highway and decrease to the west. Younger units are progressively less deformed. The overall structure appears to be that of a block or horst tilted progressively westward with time. This block was periodically partly or entirely covered by lakes that prograded eastward and by alluvial and other terrestrial deposits that prograded westward. The alluvial deposits are mostly distal fan deposits, locally interbedded with eolian and colluvial deposits.

The oldest units are exposed near the highway and consist of a conformable sequence (measured sections 9 and 10, figs. 5 and 6) of alluvial deposits (unit Tt) overlain by about 50 m of well-bedded lacustrine mudstone, siltstone, and sandstone capped by beach gravel (unit Tl), in turn overlain by a very thick (unmeasured) sequence of alluvium and eolian deposits (unit QTt) containing numerous carbonate-enriched paleosols. Units Tt and Tl both contain tephra layers but only one, EL-19-WD in unit Tt, has yet been identified; it is tentatively correlated with an upper Miocene to lower Pliocene tephra erupted from the Snake River Plain. A few vertebrate bone fragments are scattered on the surface of lacustrine unit Tl, but none have yet been identified. In the south-central part of the map area, erosion between the time of deposition of units Tt and QTt has removed unit Tl.

Terrestrial unit QTt apparently extends westward to underlie younger lacustrine units around McGee Wash (fig. 5), where it was mapped by Morrison and Davis (1984) as the Paiute Formation (fig. 2). Morrison (oral commun., 1995) now equates this to the older Lovelock Formation. Three tephra layers crop out in unit QTt in McGee Wash (EL-5-, -6-, and -57-WD), but none have yet been correlated with tephra of known age. EL-5-WD has normal polarity.

Four pre-Sehoo lacustrine units overlie unit QTt in this area and are separated by unconformities. The oldest, Qlo1, is a thin (~2 m) bed of pebble gravel grading up into silty sand. It appears to be preserved in only one place too small to show at the scale of figure 5: it is

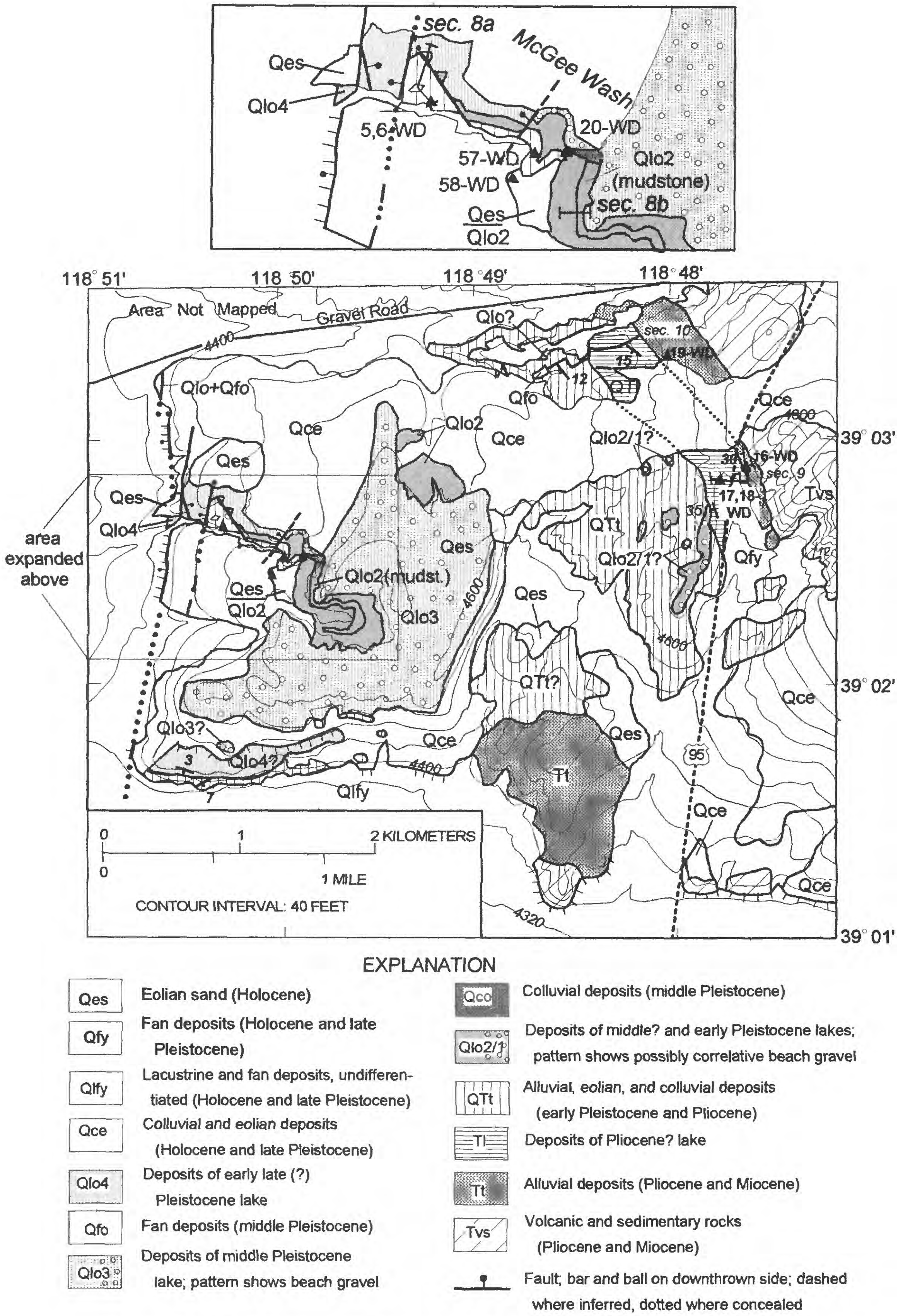


Figure 5. Geologic map of area around McGee Wash, east of Weber Dam. See figure 3 for location. Triangles with codes (e.g. 5, 6-WD) are tephra localities. Hachures show shorelines.

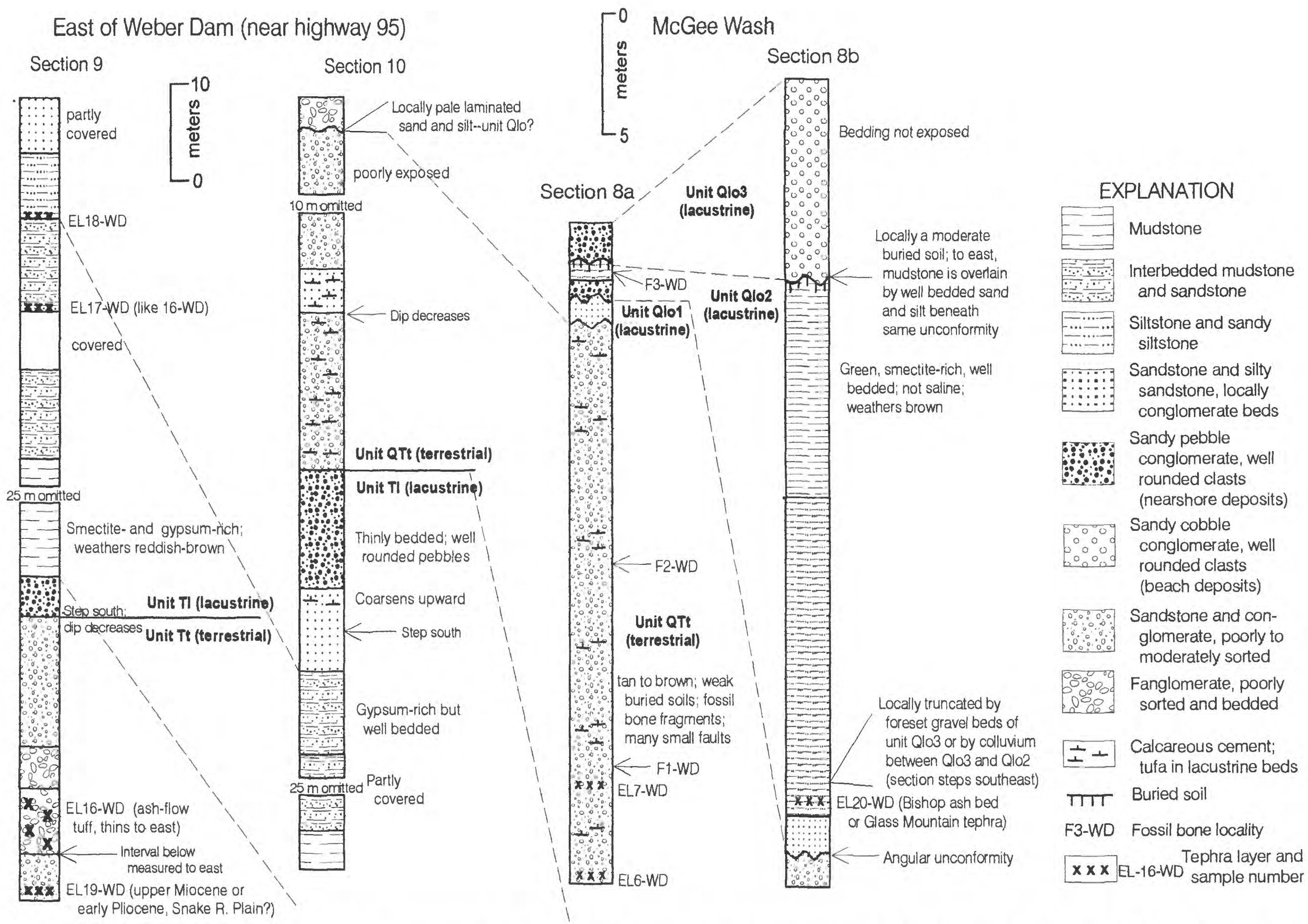


Figure 6. Measured sections of lacustrine and terrestrial deposits in the area around McGee Wash. See figure 5 for locations. Note scale difference between sections 9 and 10 near U.S. Highway 95 and sections 8a and 8b in McGee Wash.

exposed beneath unit Qlo2 near the top of measured section 8a (fig. 6), but is cut off by a fault and removed by erosion west of the fault prior to deposition of unit Qlo2. Unit Qlo2 is locally much thicker and crops out around the head of McGee Wash (fig. 5) to a maximum elevation of about 1390 m (4560 feet). This unit consists of a basal bed of sand and pebble gravel that grades up into well bedded silt and sand containing at least one tephra layer (EL-20-WD, EL-58-WD). Sample EL-20-WD near the base of measured section 8b (figs. 5 and 6) has been identified as one of the Bishop-Glass Mountain tephra layers; paleomagnetic analyses have not yet been done. A beach-pebble facies of unit Qlo2, if deposited, has mostly been removed by erosion, but remnants of beach gravel that appear to be older than that of unit Qlo3 are locally preserved capping units QTl and QTt near the highway at an elevation of about 1430 m. Unit Qlo3 unconformably overlies silt and sand of unit Qlo2 around the head of McGee Wash, and consists predominantly of loose sand and beach gravel (figs. 5 and 6). A paleosol (Bw or weak Bt and/or Bk horizon) is locally preserved at the unconformity, and in one place a reddish colluvial unit appears to be preserved between units Qlo2 and Qlo3. Unit Qlo3 is well exposed only at the south edge of the map area. In aerial photographs this unit has the morphology of a shoreline berm. The berm rises to an elevation of 1402 m (4600 feet), the same elevation as the highest shore gravel at the Thorne Bar. The youngest of the four lacustrine sequences around McGee Wash, unit Qlo4, is poorly exposed beach sand and gravel inset into all older units. This unit rises to an elevation of about 1365 m at the south edge of the map area.

Other sites in the Walker Lake basin

Campbell and Sunshine Amphitheaters are northwest of Weber Dam and lie on opposite sides of the Walker River near the point where the river bends in a U-turn (fig. 3). Both of these sites were first identified by Ken Adams as potentially preserving sediment of pre-Eetza lake cycles above the Sehoo shoreline.

Outcrops in Campbell Amphitheater are complicated by a network of north- and northwest-striking strike-slip faults of the Walker Lane. In addition, it is difficult at this site to associate areas of beach gravel that mark shorelines with exposed finer-grained sediment. Three lacustrine units are preserved (fig. 7). The oldest, Qlo1, laps onto subjacent basalt where it consists of shoreface conglomerate that grades rapidly upward into fine-grained beds. A tephra layer, EL-15-CA, drapes this facies change from shoreface into deeper-water deposits. The tephra is correlated with the Bishop-Glass Mountain family of tephra and preliminary paleomagnetic results indicate normal polarity; thus, the tephra is probably the Bishop ash bed. Unit Qlo1 is unconformably overlain by beach gravel of unit Qlo2; a paleosol (Bt/Bk) and colluvium are locally preserved at the contact. Unit Qlo2 rises to at least 1378 m, and beach pebbles that may represent this unit are lagged on basalt up to an elevation of 1390 m. The pebbles stop just below an abrupt change in slope that appears to be a preserved shoreline angle. Beach gravel of unit Qlo3 is apparently inset into the older units, and forms a berm at an elevation of 1356 m.

Sunshine Amphitheater is a very large exposure of pre-late Pleistocene lacustrine deposits of four different ages. It is remarkable for the abundance and preservation of vertebrate fossils; thus far, identified remains include those of giant sloth (J. Honey, oral commun., 1995), horse, camel, bird (C. Repenning, oral commun., 1996), and cutthroat trout (R. Miller, written commun., 1996). Faults are exposed but displacement appears to be minor, in contrast to the McGee Wash and Campbell Amphitheatre sites. The three oldest lacustrine units are relatively fine-grained in part, and have been sampled for paleomagnetic interpretation (fig. 7). Briefly, the oldest unit QTlo1 consists mainly of reversely polarized, brown laminated mudstone capped by pebbly sandstone. It is overlain by unit QTt, alluvial deposits containing carbonate-enriched paleosols. Unit QTt is conformably overlain by well bedded pebbly sandstone, siltstone, and mudstone of unit Qlo2, which also has reversed polarity. A distinctive horse bone from this unit appears to constrain the age to between 1.7 Ma and 1 Ma (C. Repenning, written commun., 1996), which is consistent with paleomagnetic data. An unconformity, locally marked by thin colluvium and a paleosol (Bw horizon), separates units Qlo2 and Qlo3. Many fossils are associated with this stratigraphic interval, including a distinctive sloth bone identified (J. Honey, oral commun., 1995) as post-Blancan in age (<2.5 Ma; Berggren et al., 1995). Unit Qlo3 consists of poorly indurated siltstone and sandstone that coarsen upward into beach gravel extending to an elevation of 1396 m. Well rounded beach pebbles mixed with fan gravel extend to an elevation of 1414 m; the pebbles may represent yet another lacustrine unit at this site. Paleomagnetic measurements from the siltstone beds indicate that this unit has reversed polarity except for an interval about 2 to 8 meters above the base, which has normal polarity. Combined with the horse bone beneath the unconformity, these data indicate that the normal interval probably correlates with the Jaramillo Normal Subchron at about 1 Ma. Thus, the three oldest lacustrine units at Sunshine Amphitheater lie within the Matuyama Reversed Chron, unit Qlo2 was deposited between 1.7 and 1.0 Ma, and unit Qlo3 was deposited at about 1 Ma (ages of Berggren et al., 1995). Unit Qlo4 consists of sandy beach gravel inset into the older units, and rises to an elevation of about 1378 m. Its paleomagnetic polarity is unknown.

Another site about halfway between Sunshine Amphitheatre and McGee Wash records shorelines cut into two basalt hills. Subdued breaks in slope on the west sides of these hills are the remains of shoreline angles. From a distance these slope breaks resemble flow contacts, but rounded beach pebbles are associated with the most prominent and consistent slope break at an elevation of 1365 m, and they are identical to pebbles that abundantly mark the Sehoo shoreline cut on the same hills at 1335 m. Additional small remnants of slope breaks may also record shoreline angles at 1353 m and 1396 m. A high shoreline is further supported by an outcrop on the east side of one of the hills. Here, well rounded gravel of rhyolite and basalt overlie a rhyolite flow weathering into angular clasts; the rounded gravel crops out as high as 1390 m.

Basins North of Walker Lake

In the late Pleistocene, the main area of Lake Lahontan was connected to the Walker Lake basin only by a narrow neck through Adrian Valley (figs. 1 and 3; Davis, 1982). A lake that rises to 1400 m in the Walker Lake basin also spills to Lake Lahontan through Rawhide Flats over a pair of sills at 1370 m (fig. 3). However, it is possible that in the early Pleistocene, Adrian Valley did not exist (King, 1993) and the sills leading into Rawhide Flats could have been higher in elevation. Hence, I sought evidence of high shorelines north of the Desert Mountains to establish that the very high shorelines found in the Walker Lake basin apply to Lake Lahontan as a whole. No such shorelines had been previously reported; however, Marty Mifflin had seen some "suspicious-looking" benches above the Sehoo shoreline during his field work in the 1960's and suggested a search in the Truckee River canyon east of Reno and in the Smoke Creek Desert north of Reno (fig. 1). Work in the Truckee River canyon has revealed some interesting geomorphic features with rounded cobbles at about 1400 m elevation, and one roadcut exposes well bedded sediment that may be lacustrine or deltaic at about 1360 m. However, these features could also be fluvial in origin. Indisputable evidence of high, old shorelines exists at three sites in the Smoke Creek Desert and potentially at one site in the northern Black Rock Desert (fig. 1). Unfortunately, no stratigraphic sequences containing tephra or other datable material of probable Quaternary age have yet been found north of the Desert Mountains.

The southern site in the Smoke Creek Desert is west of a Quaternary fault that bounds the western edge of the basin but apparently has not displaced late Pleistocene deposits (Dohrenwend et al., 1991). Two subtle benches and risers cut on basalt and rhyolite flows are defined by topographic contours. The upper bench terminates upward at a slope break at 1400 m and well rounded small pebbles of several lithologies are scattered over the bench between 1395 and 1400 m. The pebbles are not derived from alluvial beds between the flows. The lower bench is at about 1375 m and is blanketed with abundant well rounded pebbles and some pieces of lacustrine tufa (definitely not pedogenic $CaCO_3$). A few kilometers to the north, another site also has abundant well rounded pebbles at about 1390 m.

The eastern site (fig. 1) has benches and risers cut on basalt. The benches and risers are covered with basalt clasts, locally closely fitted together in pavements interspersed with rougher surfaces and on steeper slopes with matrix-poor stone stripes trending downslope. Many of the clasts on both the benches and the risers are well rounded and polished rather than being angular or subangular as is typical of clasts in colluvial block fields. The rounding and polishing require vigorous transport by water. Alluvial transport can be ruled out because the benches are laterally continuous and the topography does not permit stream erosion, even far in the past. The upper bench at this site rises gradually from about 1370 m to a subtle slope break at about 1400 m; the lower bench rises from a flat surface at 1360 m to a distinct slope break at about 1365 m.

A borrow pit in the northern Black Rock Desert exposes very well sorted, well bedded loose sand at an elevation of about 1410 m. The sand is capped by a well developed soil with an argillic horizon extending down about 1 m, and the sand overlies a well developed indurated argillic paleosol. The sand unit is too well bedded and sorted to be fan alluvium, despite its proximity to range fronts on both sides, and could represent a beach sand. The site needs to be re-excavated with a backhoe.

Summary and Implications

Several good outcrops in the Walker Lake basin document numerous high stands of a lake that rose far above the Sehoo and Eetza shorelines (fig. 3) during the early and middle Pleistocene. Stratigraphic relations among four sites (fig. 7) permit a conservative correlation of the youngest units; these units always crop out as beach gravel inset into all older units. The maximum elevations of these younger units range from 1356 to 1378 m at the three tectonically deformed sites. Unit Qlo3 at the Thorne Bar has not been deformed and its maximum elevation is about 1370 m, the same as that of the shoreline angle cut on basalt hills north of Weber Reservoir (fig. 3). Thus, I infer that these youngest units represent one or more high stands at about 1370 m, shoreline deposits and remnants of which have since been deformed. The presence of the Bishop ash bed in lacustrine deposits at the Thorne Bar and Campbell Amphitheater permits correlation of the Qlo1 units at these sites (fig. 7). Unit Qlo2 in McGee Wash contains a Bishop-like ash and may also be correlative; however, if this tephra should prove to be paleomagnetically reversed, it would be ca. 1-Ma Glass Mountain tephra and would tie this unit to that discovered by Morrison (1991; Morrison and Davis, 1984) west of Weber Reservoir. The lacustrine units overlying units containing tephra at Thorne Bar, McGee Wash, and Campbell Amphitheatre are also those that rise to the highest elevations at each site: about 1400 at the first two and about 1390 m at the latter. These data suggest, but do not prove, that these units represent the same high stand at about 1400 m elevation. Paleomagnetic data from the Sunshine Amphitheater show that the three oldest lacustrine units there are older than those at the Thorne Bar and Campbell Amphitheater, but they could be in part correlative to older units near McGee Wash. A conservative correlation among all the sites known in the Walker Lake basin (fig. 7) yields a total of six lacustrine units (other correlations would increase this number) whose shorelines exceeded those of the Sehoo and Eetza lakes; two of the units postdate the 760-ka Bishop ash bed (one of these probably correlates with the Rye Patch Formation, fig. 2), one contains the ash bed, and three predate the ash bed but are younger than 2.5 Ma.

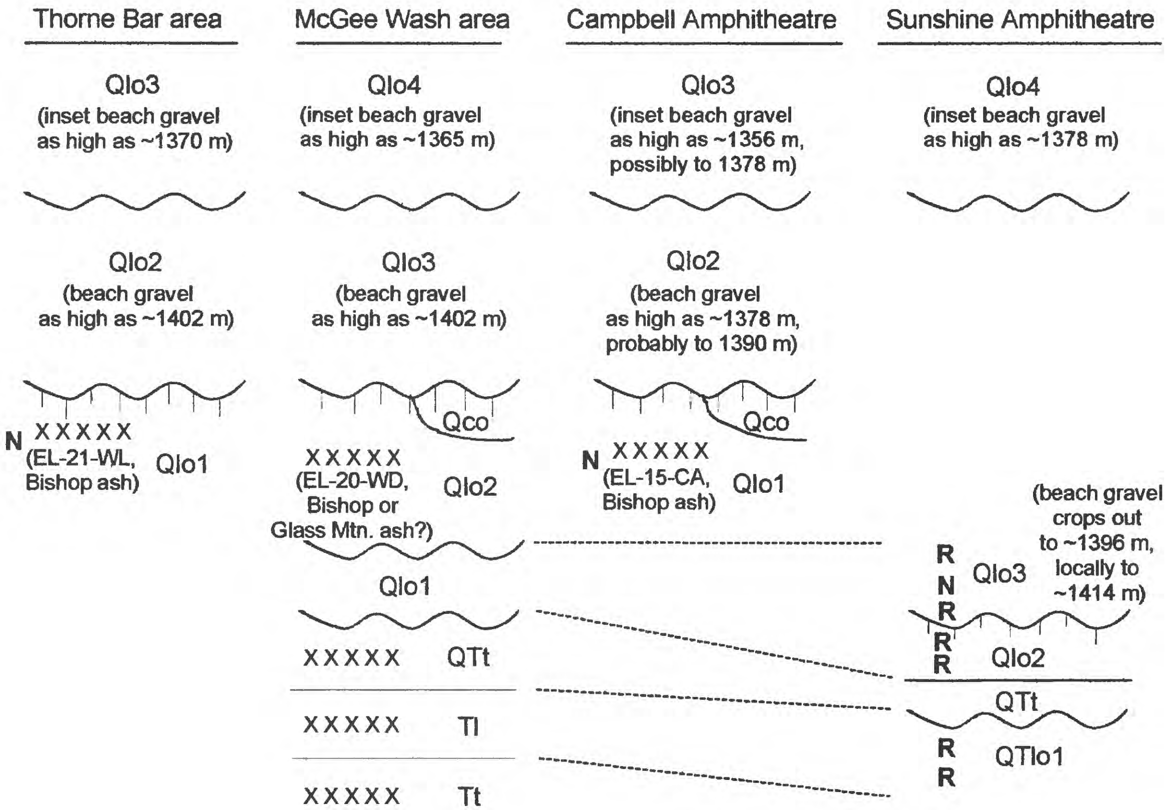


Figure 7. Preliminary stratigraphic correlations in the Walker Lake basin. Units and symbols are the same as those used in figures 4, 5, and 6, except N and R are normal and reversed polarity, respectively. Note that units with the same names in different areas may not be correlative.

Shoreline evidence from the sites in the Smoke Creek Desert indicates high stands at elevations of about 1370 and 1400 m. No age control yet exists for these sites, but the correspondence of these two shoreline elevations with those at the Thorne Bar and elsewhere in the Walker Lake basin strongly argues that they represent a continuous Lake Lahontan at two different times in the middle Pleistocene. The implications of a 1400-m shoreline are staggering (fig. 8): for example, such a lake would inundate Granite Springs Valley, would back up the Truckee and Carson Rivers to submerge all or part of present-day Reno and Carson City, would back up the Humboldt River at least to present-day Battle Mountain, and would extend 60 km southeast from Walker Lake to Rhodes Salt Marsh. If allowances are made for local tectonics and sedimentation in the past half-million years, the lake would have flooded into Dixie and Fairview Valleys and inundated many other flat-lying valleys whose floors are now only a few tens of meters above the 1400-m level. These high lake stands may prove key to understanding the distribution of native populations of fish and amphibians in the Great Basin (e.g. Hubbs and Miller, 1948; Hubbs et al., 1974).

Lake Lahontan is not the only pluvial lake in western Nevada that exhibits evidence of very high, old shorelines. Field reconnaissance has located several sites around the margin of pluvial Lake Columbus (figs. 1 and 8) that demonstrate shorelines as much as 70 m higher than the late Pleistocene level and show that this lake was once contiguous with an early to middle Pleistocene Lake Rennie in Fish Lake Valley (Reheis et al., 1993). Very high shorelines are also preserved on the eastern side of Mono Lake; during this high stand, Mono Lake may have drained north into the Walker River rather than south into the Owens River (fig. 8). Together, these findings suggest that western Nevada was much wetter during pluvial periods of the early and middle Pleistocene than during those of the late middle to late Pleistocene. The reasons for

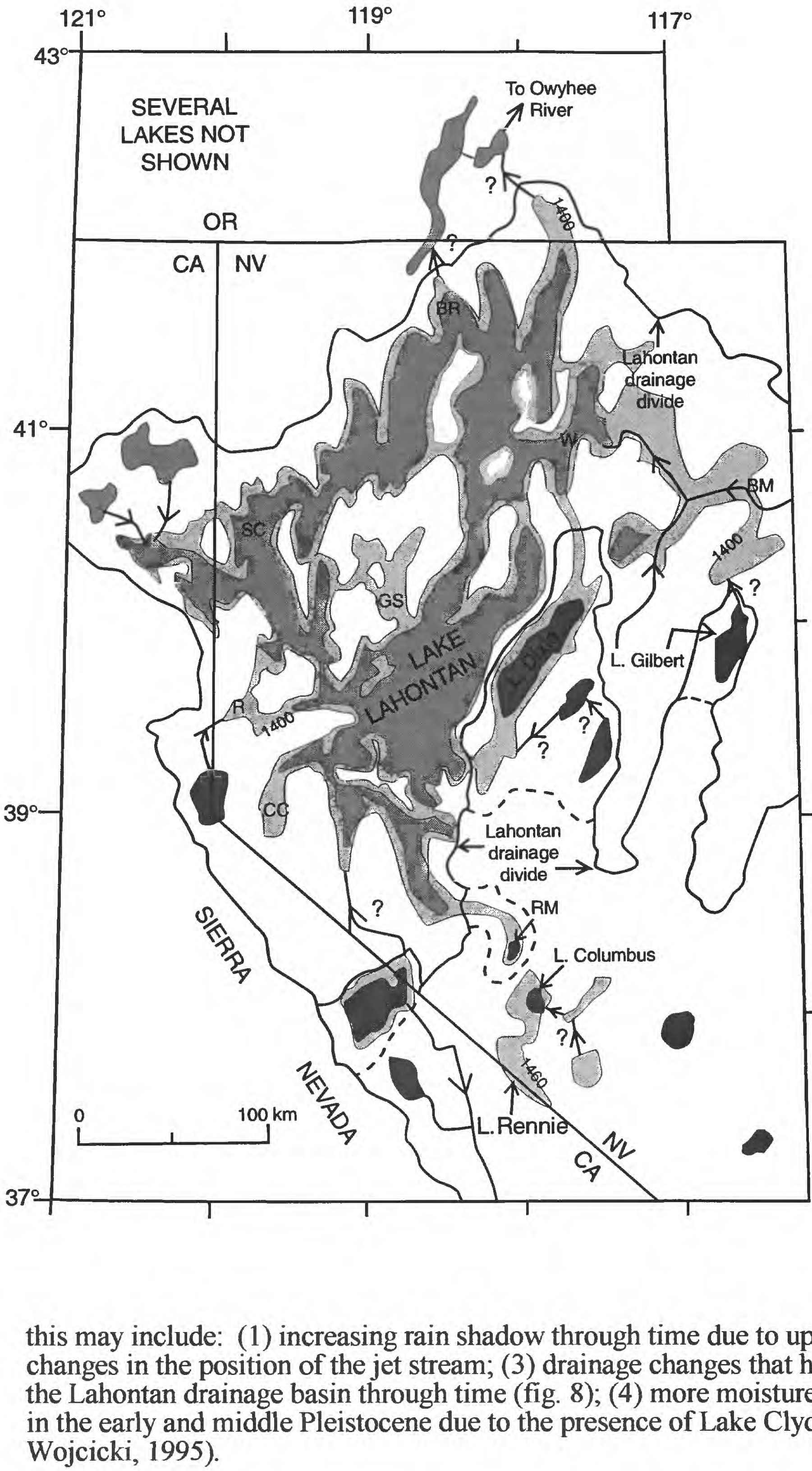


Figure 8. Regional map showing Lahontan basin, selected shoreline elevations in meters, and areas of middle (lightest shading) and late (medium and dark shading) Pleistocene lakes. Queried arrows on drainages show possible links between basins during highest lake stands; dashed lines show possible enlarged area of Lahontan basin. BR, Black Rock Desert; W, Winnemucca; BM, Battle Mountain; GS, Granite Springs Valley; R, Reno; CC, Carson City; RM, Rhodes Salt Marsh.

this may include: (1) increasing rain shadow through time due to uplift of the Sierra Nevada; (2) changes in the position of the jet stream; (3) drainage changes that have diminished the size of the Lahontan drainage basin through time (fig. 8); (4) more moisture crossing the Sierra Nevada in the early and middle Pleistocene due to the presence of Lake Clyde east of the range (Sarna-Wojcicki, 1995).

Contributions to Road Log

Day 2, Stop 3, Highway 95 roadcut east of Weber Reservoir

Please watch out for traffic and remember we are guests on the Walker River Paiute Reservation!

From the area of the highway west to the Walker River at Weber Reservoir is a large area of pre-late Pleistocene lacustrine and terrestrial deposits. These are described in detail, including a geologic map and measured sections, in Reheis (figs. 5 and 6, this guidebook). Exposed on both sides of the highway are late Miocene(?) to early Pleistocene(?) alluvial and lacustrine deposits that dip 25-30° west. Measured section 9 begins in Tertiary alluvium (unit Tt) east of the highway and ends at the top of a younger lacustrine unit (Tl) west of the highway. A partially overlapping and longer section 10 that extends up into the next younger terrestrial unit, QTt, was measured about 1 km northwest of here. All of these units contain tephra layers. The tephra in unit Tl are marker beds that show that these rocks are closely faulted and that the faults have small displacements (west side of roadcut). The only tephra that has been identified is in unit Tt near the bottom of section 10; it is probably a late Miocene or early Pliocene tephra erupted from the Snake River Plain (A. Sarna-Wojcicki, oral commun., 1996). At the top of the western cut, a remnant of much younger beach gravel of a former lake (unit Qlo1 or Qlo2?) lies unconformably on both units Tl and QTt at an elevation of about 1433 m, the highest such outcrop yet found in the Walker Lake basin. *Bone fragments occur locally as lag on these outcrops; please do NOT collect any.*

Day 3, Stop 1, McGee Wash

McGee Wash, named by Roger Morrison for W H McGee of the Russell expedition, exposes deposits of four pre-late Pleistocene lacustrine lakes that lie above the Sehoo level (1330 m, 4360 feet). We will walk up this wash about 2 km to see the evidence for these lakes (note that the youngest, Qlo4, is not well exposed here). Much of the lower part of the wash is shown as a stratigraphic cross section in figure 2-7 of Morrison and Davis (1984). See Reheis (figs. 5 and 6, this guidebook) for detailed descriptions, a geologic map, and measured sections of this area; the map overlaps Morrison and Davis' cross section at the western edge of figure 5.

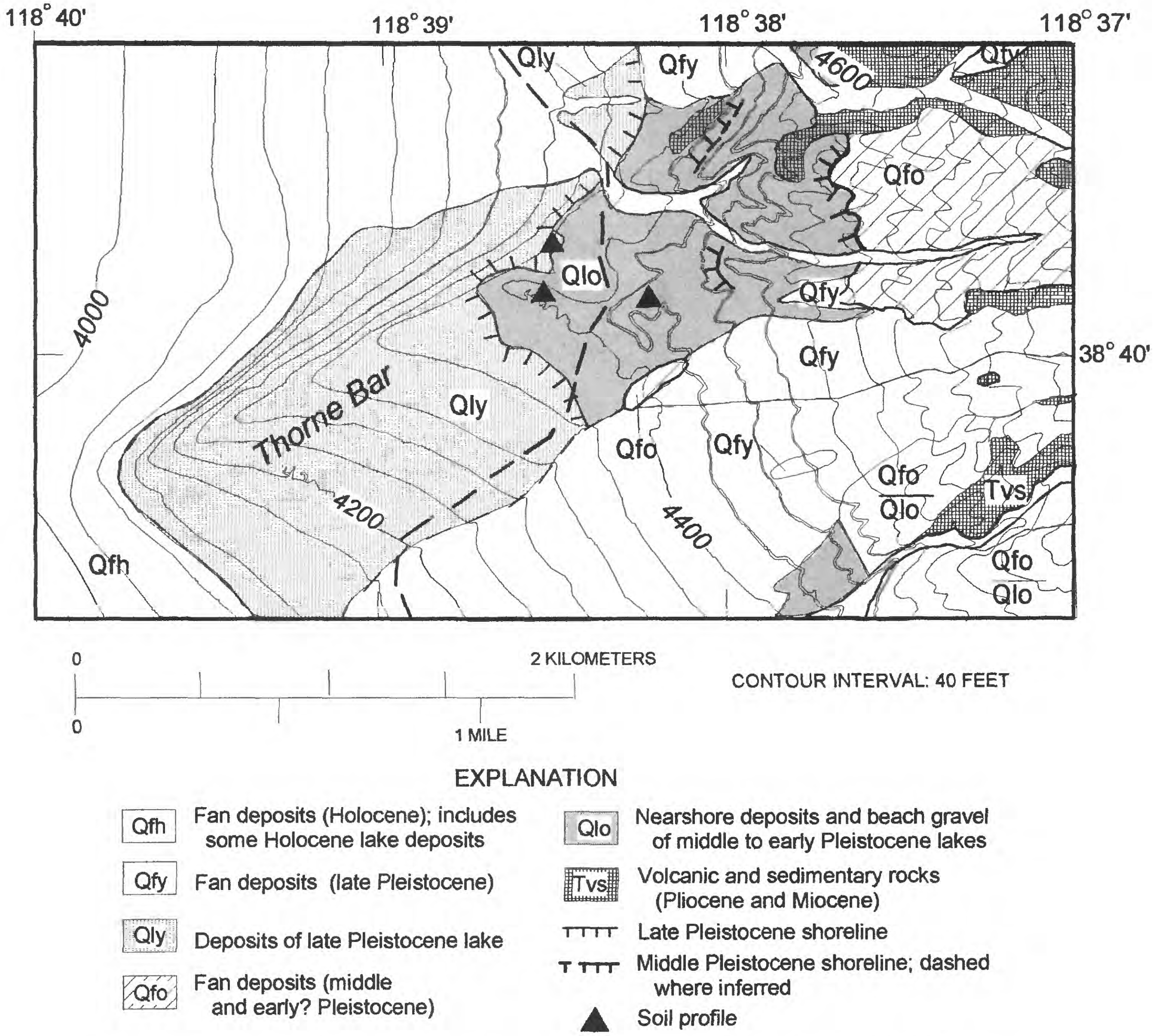
Terrestrial unit QTt is exposed at the base of much of the upper part of McGee Wash and underlies the four lacustrine units; unit QTt is equivalent to the Paiute Formation shown by Morrison and Davis (1984), which Morrison now equates to the older Lovelock Formation. Unit QTt is sequentially overlain by lacustrine units Qlo1 (only preserved in one small outcrop), Qlo2, and Qlo3, all separated by unconformities. Lacustrine deposits here consist mostly of well bedded sandy pebble gravel and siltstone, although the upper part of unit Qlo2 also includes a thick lenticular bed of mudstone that may have accumulated behind a barrier bar. Unit Qlo2 contains tephra, one sample of which has been correlated with the Bishop-Glass Mountain family of tephra. The highest outcrop of lacustrine deposits in this area is a curving berm-shaped feature composed of sandy beach gravel that rises to an elevation of 1400 m (4600 feet). Although faulting is common in this area, the coincidence of the altitude of this well-preserved berm with that of other shoreline remnants in unfaulted areas (Thorne Bar and Sunshine Amphitheater) indicates that faulting is not solely responsible for the high elevation of this berm.

Day 3, Stop 3, Thorne Bar

The Thorne Bar is a large V-shaped bar of shore gravel built at the mouth of a large canyon draining the Gillis Range. See Reheis (fig. 4, this guidebook) for a detailed discussion and geologic map of the area. The bar was previously described by King (1978), Mifflin and Wheat (1979), and Morrison (1991) as an outcrop of lacustrine gravel much higher than the Sehoo shoreline; they believed that the high elevations were due to tectonic deformation. However, there appears to be no Quaternary deformation on this side of the Walker Lake basin (Demsey, 1987). The Thorne Bar consists mainly of well rounded gravel reworked from older fan deposits, with bedding ranging from horizontal to angles of 25° or more (foreset and backset beds). The bar can be divided into three morphologic units: the lowest and youngest is a sharp, well preserved V-bar marked at the top by the Sehoo shoreline at about 1330 m (ca. 4360 feet, see map in road log). Between 1330 m and about 1370 m (4500 feet), the bar consists of two nested, eroded V-shaped bars; the lower bar is better preserved than the upper. Between 1370 and 1402 m (4600 feet) the bar has no preserved morphology, but deep arroyos expose well-bedded, tufa-cemented shore gravel, and beach pebbles locally occur as lag on basalt outcrops. The degree of morphologic preservation and three reconnaissance soil pits strongly suggest the presence of at least four and probably more lacustrine units: the Sehoo-aged bar, older bars that reached elevations between 1335 and 1370 m, and at least one old bar that reached a minimum elevation of 1402 m.

Day 3, Optional Stop 4, North of Thorne Bar *(Only continue to this outcrop with a high-clearance vehicle; 4-wheel drive is useful but not required.)*

An excellent small outcrop about 4 km north of the Thorne Bar (fig. 4) exposes two sequences of high shore gravel separated by a tephra and a paleosol. See Reheis (fig. 4, this guidebook) for a measured section and detailed description of this outcrop. The lower unit consists of a shoreface gravel that fines upward into silty sand containing tephra and a paleosol with an oxidized Btk horizon. Based on chemical correlation and paleomagnetic measurements, the tephra is probably the 760-ka Bishop ash bed. The paleosol is overlain by tufa-cemented, well bedded pebble and cobble shore gravel that rises to an elevation of about 1395 m. Thus, the oldest and highest shoreline in this area is underlain by deposits of two different lakes: one that culminated at about the time of the eruption of the Bishop ash bed at 760 ka and reached a minimum elevation of about 1355 m, and a second that postdated the Bishop ash and rose to a minimum elevation of about 1400 m.



Geologic map of area of Thorne Bar, stop 3, day 3 (see fig. 3 in Reheis, this volume, for location). Heavy dashed line is county gravel road.

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