Text and references to accompany Nevada Bureau of Mines and Geology Map 168

Geologic Map of the Lahontan Mountains Quadrangle, Churchill County, Nevada

by

John W. Bell[1], S. John Caskey[2], and P. Kyle House[1]

[1]Nevada Bureau of Mines and Geology, University of Nevada, Reno
[2]Department of Geosciences, San Francisco State University

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INTRODUCTION

The Lahontan Mountains quadrangle is located 11 km east of Fallon, Nevada at the southeastern margin of the Carson Sink (Fig. 1). Principal physiographic features include the Lahontan Mountains, collectively consisting of Sehoo, Eetza, Salt Wells, and Rainbow mountains. This quadrangle is part of the greater Lake Lahontan area that in part occupied the southern Carson Desert, previously mapped by Roger B. Morrison between 1947 and 1950. The products of Morrison's studies are contained in the 1964 U.S. Geological Survey Professional Paper 401, "Lake Lahontan: Geology of the southern Carson Desert, Nevada", which stands as a seminal study on late Pleistocene Lake Lahontan in western Nevada, and provides the fundamental basis for all subsequent studies of Lake Lahontan geology, including this one. The subtitle to Professional Paper 401 accurately describes the significance of Morrison's contribution to the field of Quaternary geology in the Great Basin:

> "*A stratigraphic study of the late Cenozoic geology of the basin of Lake Lahontan, one of the great late Pleistocene lakes of western United States.*"

Morrison's study built on the pioneering stratigraphic observations of Russell (1885) who spent considerable time in the Carson Desert and identified and described key Lake Lahontan localities. These localities together with those described by Morrison are classical sites that are still visited by Quaternary geologists interested in better understanding this great late Pleistocene lake.

We undertook this study of the Lahontan Mountains quadrangle for several reasons. First, the Lahontan Mountains quadrangle provides much of the record for late Pleistocene and Holocene alluvial and lacustrine deposits in the region. It contains several of the type localities for the formations of the Lahontan stratigraphy defined by Morrison, in particular, the Eetza, Sehoo, and Wyemaha formations and the Churchill soil, stratigraphic units that are ubiquitous throughout the 21,000 km^2 area occupied by Lake Lahontan. Initially defined as time-stratigraphic units by Morrison (1964), he later redefined their formational status as allostratigraphic units (Morrison, 1991) based on stratigraphic and geomorphic relations developed in this area. The original mapping of the Lahontan Mountains by Morrison (1964) was at a scale of 1:31,680, and we believed that larger scale mapping could enhance and complement Morrison's maps. Second, Morrison developed most of the Lake Lahontan stratigraphic relations prior to the development of radiocarbon dating and tephrochronology, and thus his Professional Paper contained no numerical age data. The first radiometric dating of Lake Lahontan deposits in this area was reported by Broecker and Kaufman (1965) which contained about a dozen ^{14}C dates on middle Sehoo samples collected by Morrison in the Lahontan Mountains. We believed that a systematic re-mapping of the Lahontan Mountains type localities combined with new radiocarbon dating and new tephrochronologic age control could help improve numerical age control in this sparsely dated, but important, stratigraphic locality. Lastly, Morrison's mapping was done prior to the Rainbow Mountain-Stillwater earthquakes in 1954, and thus did not delineate the fault rupture traces. We previously conducted a detailed study of the 1954 surface faulting in the vicinity of Rainbow Mountain (Caskey et al., 2004), and we have incorporated some of those results into this study.

Geologic mapping of the adjacent Grimes Point quadrangle (Fig. 1) which includes the western margin of the Lahontan Mountain is in progress, and some of the new stratigraphic relations and numerical age data from this on-going study are included herein.

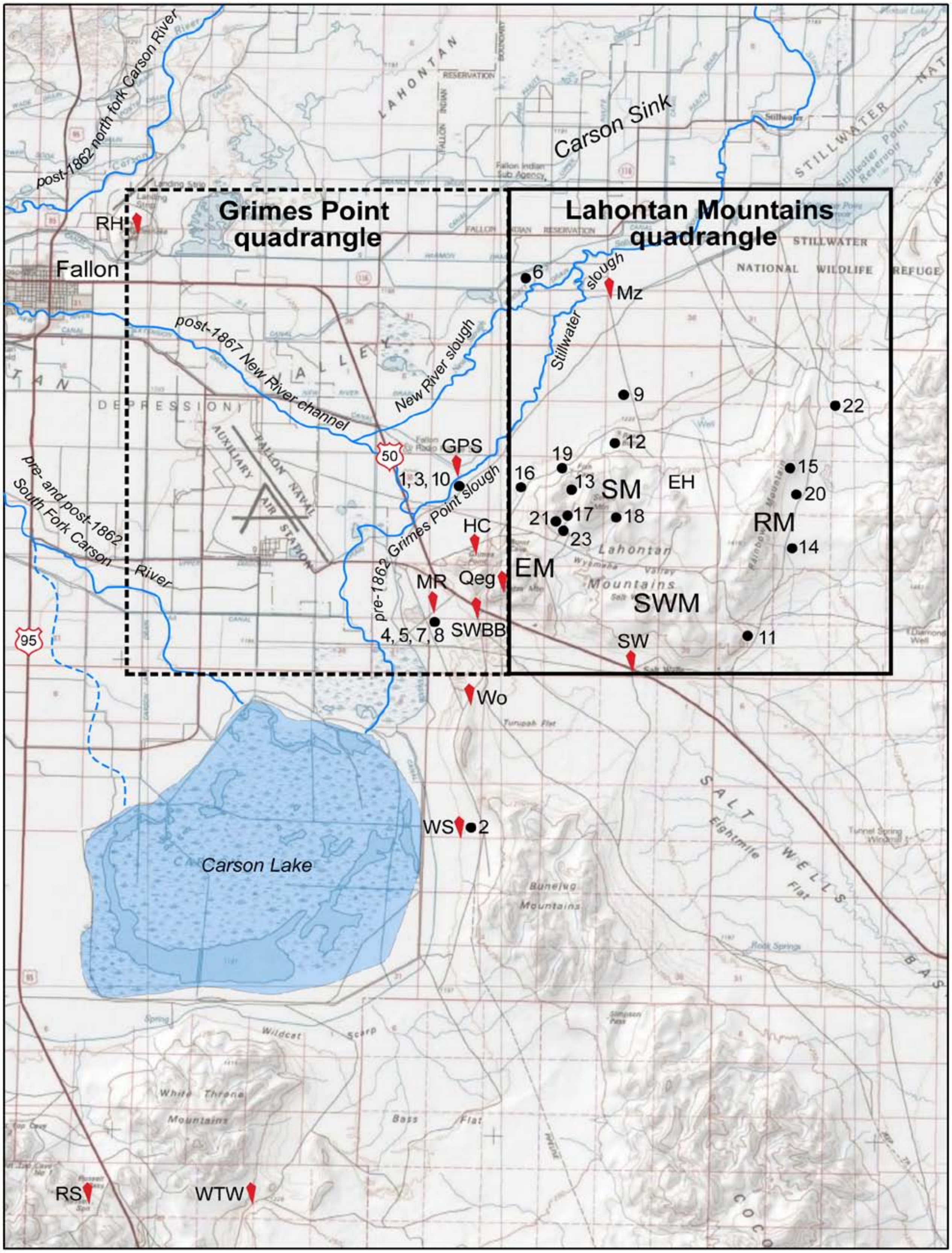

Figure 1. Map showing location of Lahontan Mountains and Grimes Point quadrangles, physiographic features, regional site localities (red arrows), and radiocarbon date locations (black circles with sample number from Table 1): EH, Eagles House, EM, Eetza Mountain; GPS, Grimes Point slough radiocarbon site; HC, Hidden Cave; MR, Macari Road radiocarbon site; Mz, Mazama tephra site; Qeg, high Eetza gravel bar of Morrison (1964); RH, Rattlesnake Hill; RS, Russell Spit; SW, Salt Wells; SWBB, Salt Wells beach barrier; SM, Sehoo Mountain; RM, Rainbow Mountain; Wo, Wono ash site; WS, Wildcat scarp; WTW, White Throne Wash. Courses of the Carson River taken from Russell (1885) and Morrison (1964).

Miocene through late Holocene age deposits comprise the late Cenozoic stratigraphy in the Lahontan Mountains (Fig. 2). Miocene basaltic, dacitic, and rhyolitic flows and intrusives occur at Rainbow Mountain (Fig. 3) and at Eagles House. These igneous rocks are unconformably overlain by Tertiary sediments. All of these Miocene rocks and sediments are strongly faulted and tilted locally, and are capped unconformably by flat-lying or gently dipping basalt flows of probable late Miocene or Pliocene age. The Tertiary volcanic-sedimentary section is unconformably overlain in the Lahontan Mountains by middle to late Pleistocene deposits of the Lake Lahontan sequence, with the most recent deposits of Holocene age associated with alternating cycles of shallow lake and fluvial (Carson River) deposition.

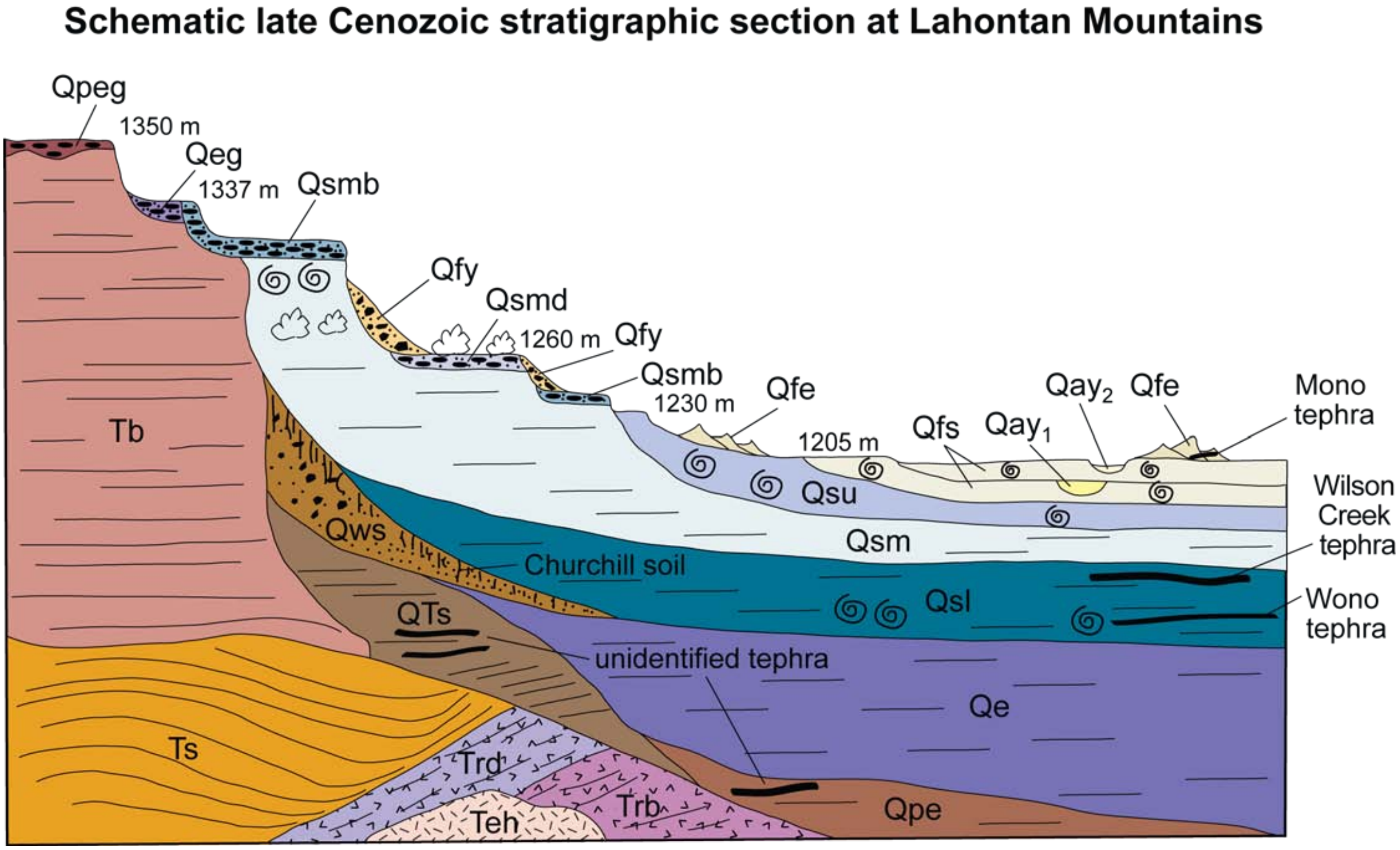

Figure 2. Schematic stratigraphic section showing bedrock and overlying Quaternary unit relations in the Lahontan Mountains quadrangle. Not to scale.

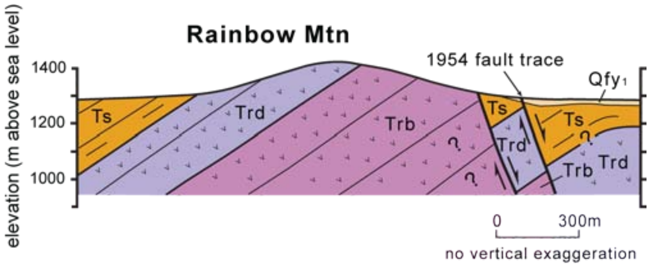

Figure 3. Schematic section showing Tertiary stratigraphic and structural relations across Rainbow Mountain. Not to scale.

Lake Lahontan and related interlacustral deposits were given originally given formal formational status by Morrison (1964), cf., Eetza, Sehoo, Wyemaha, and Fallon Formations. Later, Morrison (1991) reclassified these units as alloformations to be consistent with the North American Code of Stratigraphic Nomenclature, and this is the convention that we followed in this study.

BEDROCK GEOLOGY

Nomenclature of Tertiary Map Units

Morrison (1964), in his study of the geology of the southern Carson Desert, informally divided the Tertiary volcanic and sedimentary units within the Lahontan Mountains quadrangle into (from oldest youngest): the basalt of Rainbow Mountain; the dacite of Rainbow Mountain; the rhyolite of Eagles House; the Truckee formation; and the Bunejug formation. We largely follow the previous bedrock nomenclature put forth by Morrison (1964). However, we adopt a general, informal designation for the locally heterogeneous collection of Tertiary sedimentary rocks (Ts) in the Rainbow Mountain area that Morrison originally assigned to the once-considered, more regionally inclusive Truckee formation. We also refer to the capping basalt flows in the Lahontan Mountains area, previously assigned to the Bunejug formation (Morrison, 1964), simply as (late) Tertiary basalt flows (Tb).

Tertiary Rocks

Morrison's original (1964) report includes detailed and generally complete descriptions of the lithologic and petrologic characteristics of the Tertiary units in the Lahontan Mountains including his lithologic correlations to rocks exposed in neighboring parts of the southern Carson Desert, namely in the White Throne, Bunejug, and Cocoon mountains to the south. For this reason, only brief summaries of the Tertiary unit descriptions are included herein. The mapped distributions and field observations of Tertiary units and relations between units in the Lahontan Mountains are also in general agreement with the previous mapping of Morrison (1964), several exceptions of which are noted in the descriptions below.

Basalt of Rainbow Mountain (Trb)

Basalt and/or andesite flows of the map unit Trb are extensively exposed at Rainbow Mountain. The unit consists of pervasively altered and largely silicified interbeds of dark-greenish-gray and dark-brownish-gray, ledge-forming basalt flows and dark-reddish-brown and medium-to-dark-gray slope-forming units (Fig. 4A) interpreted by Morrison (1964) as mafic tuffs and volcanic breccias. The flows are mostly vesicular and generally vary from less than a meter to several meters in thickness. The exposed thickness of the unit is estimated from map relations to be a minimum of 150 m. The base of the unit is not exposed.

Trb is intruded throughout the Rainbow Mountain area by less-altered basaltic sills and dikes (Fig. 4B). These younger, mafic intrusive rocks mostly occur as sills, which are often difficult to distinguish from the older, host basalt flows. The sills and dikes are mapped in detail for only the central part of Rainbow Mountain. However, the mafic sills and dikes are thought to be extensively distributed throughout most areas mapped as Trb.

A small outcrop of probable Trb basaltic andesite occurs along the southern flank of Eetza Mountain, and it is the only occurrence of Trb east of Rainbow Mountain in the map area.

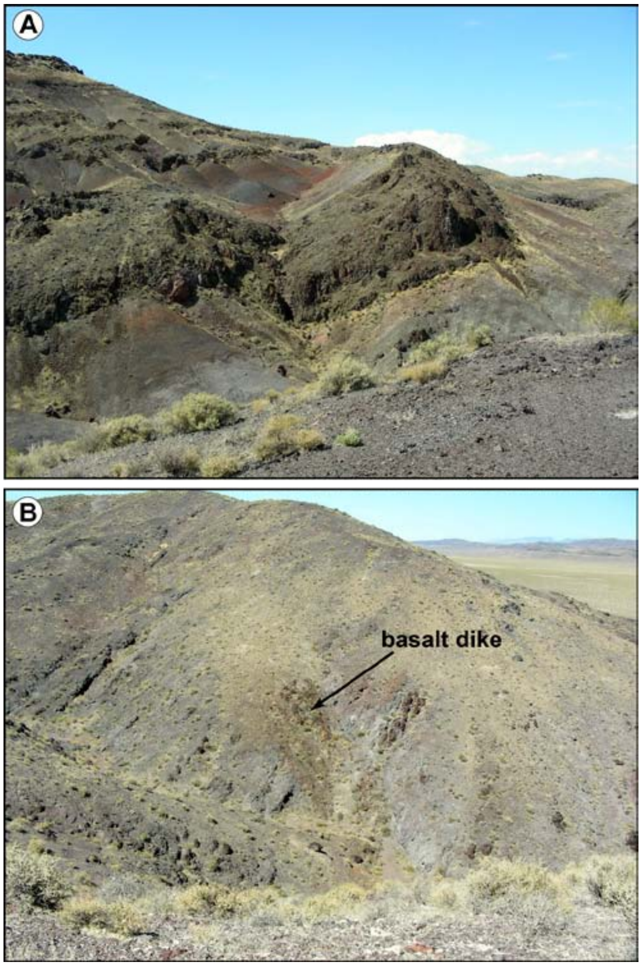

Figure 4. Typical exposures of the basalt of Rainbow Mountain (Trb). **4A.** View looking northwest across the east flank of Rainbow Mountain at west-dipping beds of the basalt of Rainbow Mountain (Trb). Trb is characterized by highly altered, silicified ledge-forming basalt flows and intervening, slope-forming tuffs and breccias. **4B.** Olive-green basalt dike cutting the west-dipping beds of Trb.

Dacite of Rainbow Mountain (Trd)

The dacite of Rainbow Mountain (Trd) consists primarily of light-to-medium gray and pinkish gray, distinctly flow-banded volcanic flows. The unit is best exposed along the highest ridges in the central and southern parts of Rainbow Mountain. Morrison (1964) describes rocks of this unit as ranging from quartz latite to rhyolite in composition. The unit locally contains conspicuous, dispersed, angular clasts of porphyritic basalt around which the flow banding is distorted.

Trd concordantly overlies the older basalt flows of Rainbow Mountain (Trb) along an abrupt depositional contact. The dacite is moderately hydrothermally altered locally, although much less so than the pervasively altered and older flows of Trb. The exposed thickness of Trd estimated from map relations is approximately 60 m. Trd also occurs in slope exposures along the lower southeastern flank of Eetza Mountain which Morrison (1964) mapped as the rhyolite of Eagles House (Teh). However, examination of several adjacent outcrops shows that the rocks are dacite flows and tuffs with a basal vitrophyre indicating that the rocks are part of the dacite of Rainbow Mountain. They overlie an outcrop of probable Trb basaltic andesite, and, as noted above, these are the only exposures of these volcanic rocks east of Rainbow Mountain in the map area.

Rhyolite of Eagles House (Teh)

The rhyolite of Eagles House is exposed in an approximately 2 km^2 area between Rainbow and Sehoo Mountains. The unit consists of light gray to pinkish gray, porphyritic, quartz-biotite-sanidine(?)-hornblende rhyolite, locally exhibiting a medium crystalline texture that borders on phaneritic. Teh contains complex flow-layering with common steep-to-subvertical foliation, especially in the vicinity of Eagles House peak. The phaneritic-like texture of the rhyolite together with the presence of subvertical flow layering and the very localized nature of the unit suggest that it may represent an exhumed volcanic plug. Alternatively, Morrison (1964) interpreted the rhyolite of Eagles House as a series of extrusive lava flows.

The stratigraphic relations between Teh and the mafic and felsic volcanic flows at Rainbow Mountain (Trb and Trd, respectively) are uncertain. Subaerially deposited sediments of Ts clearly rest depositionally on the rhyolite approximately 600 m northwest of Eagles House peak. Hence, if the rhyolite of Eagles House was emplaced as a shallow intrusive (e.g., a volcanic plug), exhumation of the rhyolite predates the age of Ts deposition in this area. The unit appears to be moderately hydrothermally altered locally.

Tertiary sedimentary rocks and sediments (Ts)

Ts consists of a heterogeneous assemblage of sedimentary rocks and poorly consolidated sediments consisting of sandstone, siltstone, pebbly sandstone, fine-pebble conglomerate, tuffaceous sandstone and siltstone, lithic tuff, pumiceous tuff, diatomite, and minor limestone. About 2 km northeast of Eagles House, Ts contains a conspicuous rhyolitic pyroclastic agglomerate (Tsp) exposed only in a narrow area of young channel cuts. In this area an estimated 10+ m thick section of the agglomerate contains coarse pumaceous blocks and bombs up to 40 cm in diameter. At the northeastern edge of Rainbow Mountain, Ts also contains several interbeds of olivine basalt flows (Tsb) which are well exposed just east and west of the main road.

The sediments of Ts are mostly slope-forming units exposed on low-lying surfaces scoured by pluvial Lake Lahontan shoreline processes, in younger channel cuts along the eastern flank of Rainbow Mountain, and locally throughout the broad area between Rainbow and Sehoo Mountains. The unit is highly silicified and liesegang banded (i.e., altered to varicolored wonderstone) locally. Where silicified and altered, the unit generally forms small resistant peaks and ridges. In the area between Eagles House peak and Sehoo Mountain, the unit also contains a number of conspicuous, northeast-trending zones of travertine-supported breccia in which silicified wonderstone is pervasively brecciated and supported within a travertine matrix, presumably marking hydrothermal activity along zones of faulting. The clasts within the travertine-hosted breccia zones are highly angular and consist exclusively of previously silicified, varicolored wonderstone, which are supported by the travertine matrix.

Diatomaceous sediments of Ts depositionally overlie Trb basalt flows along the northwestern flank of Rainbow Mountain (Fig. 5). Alluvial sediments of Ts nonconformably overlie the rhyolite of Eagles House in exposures approximately 600 m northwest of Eagles House peak. Along the northeasternmost flank of Rainbow Mountain, interbedded diatomaceous and clastic sediments of Ts are locally interbedded with olivine basalt flows (Tb).

Figure 5. Multi-colored, tilted, diatomaceous silt and clay Ts sediments overlying Trb basalt flows along the northwest flank of Rainbow Mountain.

The overall thickness of Ts is difficult to estimate due to the generally poor exposures and deformation of the unit. Morrison (1964) suggested that this unit (his Truckee formation) is at least 120 m thick in the Lahontan Mountains area. However, Ts strata are locally exposed throughout the broad area between Rainbow Mountain and Sehoo Mountain, where they generally have moderate westerly dips. Map relations in this area allow for an estimated stratigraphic thickness of greater than 1000 m, although there are considerable uncertainties in this estimate due to the potential for concealed structures.

Tertiary basalt flows (Tb)

Late Tertiary basalt flows are the most extensively exposed bedrock unit in the Lahontan Mountains quadrangle and these flows form the topographic highs referred to as Sehoo, Eetza, and Salt Wells mountains. Basalt flows of Tb are also mapped along the northeasternmost flank of Rainbow Mountain and approximately 3 km east of Rainbow Mountain along the eastern boundary of the quadrangle. The unit consists of dark-brownish-to-blackish gray, commonly vesicular basalt flows and flow breccias. The basalt is locally porphyritic with fine-to-medium phenocrysts of olivine and plagioclase.

The basalt flows of Tb depositionally overlie sedimentary deposits of Ts nearly everywhere. The Tertiary basalt flows are essentially unaltered and much less deformed than underlying Ts sediments. This is particularly evident along the east flank of Sehoo Mountain, so the contact between Tb and Ts is generally considered to be an angular unconformity. Also along the east side of Sehoo Mountain the basal flows of Tb appear to lie unconformably on a thin (0.5-m-thick), poorly exposed section of mixed-source alluvium (not mapped) that contains clasts derived from Ts and Teh and overlies Ts in this area.

QUATERNARY GEOLOGY

Pre-Lahontan lacustrine deposits

Older lacustrine and alluvial sediments (QTs)

A small outcrop of pre-Lahontan fluvial/lake sediments (QTs) is exposed very locally in a deep wash cut midway between Sehoo and Rainbow mountains, which Morrison (1964) mapped as older Quaternary lake deposits. They consist of flat-lying, crossbedded, and planar bedded sand, silt, mudstone, and diatomaceous siltstone, and rounded pebble-cobble channel conglomerate. The section also contains a distinct tufa-cemented pebble conglomerate. The finer grained units contain two unidentified tephra layers; major element glass chemistries of the two beds did not match any known Quaternary tephra deposits (N. Foit, Washington State University; E. Wan, U.S. Geological Survey, 2008, written commun.). Clasts within the channel conglomerate consist almost entirely of micaceous pumice. The exposed sequence appears to represent fluvial and/or fluvial-lacustrine sediments. The deposits may be part of the older Tertiary sedimentary rocks and sediments (Ts), but owing to the flat-lying character of the sediments, we allow for the possibility that they are considerably younger than the adjacent, tilted Tertiary deposits exposed in nearby channel cuts.

Pre-Eetza lake deposits (Qpe, Qpeg)

Pre-Eetza lake sediments (Qpe) occur in the large borrow pit in Wyemaha Valley where they underlie beach gravels of Eetza age. Thin-bedded silt and mud deposits outcrop near the bottom of the pit at an elevation of 1236 m. A 1-cm-thick tephra bed occurs in the sediments on the west side of the pit, but major-element glass chemistry identification was inconclusive. While we cannot preclude the possibility that the sediments are of early Eetza age, they appear to be separated from the Eetza gravels by a strongly developed soil suggesting that they are of pre-Lahontan age. The deposits may correlate with the Rye Patch alloformation (Morrison, 1991) or with similar pre-Eetza lacustrine deposits in the lower Truckee River Canyon (Bell et al., 2005).

Scattered patches of subangular to subrounded and locally rounded cobble gravel (Qpeg) occur at elevations of 1340–1367 m in several locations on Salt Wells, Sehoo, and Eetza mountains (Figs. 6A, 6B). The gravels are distinguished from colluvial gravels derived from the underlying basalt by a higher degree of clast rounding and in the case of those on Salt Wells Mountain by subtle beach bar morphology. These gravel remnants lie above the elevation of the highest known Eetza gravels (1336 m) and are possibly correlative with part of a similar set of high-level beach gravels found at elevations of 1350–1370 m on Thorne Bar at Walker Lake and elsewhere in the western Basin and Range (Adams and Wesnousky, 1999; Reheis et al., 2002). The occurrence of Bishop/Glass Mountain ash in one of the high beach gravels at Thorne Bar indicates that at least one of the pre-Eetza lakes is 0.76–1.2 Ma in age (Reheis et al., 2002). Shorelines at 1350 m and 1370 m elevation at Thorne Bar yielded ^{36}Cl and U-series ages of 130–150 ka and 210–240 ka, respectively (M. Reheis, 2008, written commun.).

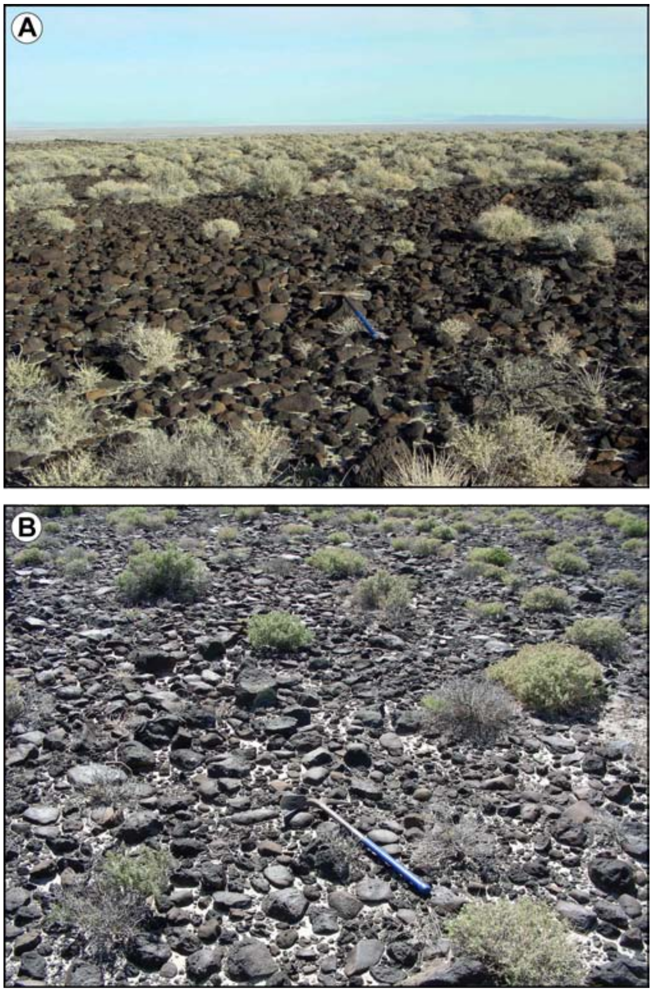

Figure 6. Surface remnants of pre-Eetza cobble beach gravel. **6A**. Subround to round beach cobbles of pre-Eetza on top of eastern Sehoo Mountain at an elevation of 1366 m. **6B**. Subround to round beach cobbles on Salt Wells Mountain at an elevation of 1346 m.

Lake Lahontan deposits

Eetza Alloformation (Qeg)

Initially called the lower lacustral clays by Russell (1885), the Eetza alloformation consists of two facies: a deep water fine-grained sequence of silt, clay, and mud, and a gravelly wave-washed beach deposit. Only the beach gravel facies has been found in this quadrangle, but the fine-grained facies undoubtedly underlies the Carson Lake area. The type locality of the Eetza alloformation is a deep canyon on the south side of Eetza Mountain on the Grimes Point quadrangle just to the west. Qeg deposits are generally found in buried stratigraphic context with the best exposures previously occurring in the gravel pits in Wyemaha Valley. Here, Eetza beach gravel (Qeg) is overlain by Sehoo beach gravel, separated by the strongly developed, argillic Churchill soil. These exposures have historically provided some of the best stratigraphic evidence for the relative age difference between the two lacustrine deposits. The exposures from these pits shown in Morrison (1964) and found again in 1980 (Fig. 7A) are no longer visible, but similar exposures are partially visible in the present-day Wyemaha Valley borrow pits. Several short bulldozer trenches at an elevation of 1270 m on the Sehoo Mountain hill slope above Wyemaha Valley expose a sequence of three beach gravels separated by two strongly developed soils (Fig. 7B). The upper gravel is of Sehoo age, and it lies on a strongly developed Bk soil developed in Qeg beach gravel. The Qeg gravel overlies a similar strongly developed soil occurring in older beach gravel.

The Eetza Alloformation was interpreted by Morrison (1991) to be associated with one or more lacustral cycles occurring during oxygen isotope stages 6, 8, and 10, and the age of the deposits was placed at between 130 and 350 ka. In the lower Truckee River Canyon above Pyramid Lake, upper Eetza lake sediments contain a 150–200 ka tephra bed (Bell et al., 2005). In the greater Carson Desert, Morrison (1991) reported uranium-series ages ranging between 110 and 288 ka for Eetza deposits; Broecker and Kaufman (1965) reported two uranium-series ages from Wyemaha Valley at 120 ka and >250 ka.

Morrison’s (1964) mapping delineated extensive areas of Eetza beach gravel on most hillslopes throughout the Lahontan Mountains. We found these delineations to be puzzling because these same hillslopes were also inundated by younger Sehoo-age lakes that overprinted earlier shorelines and shoreline deposits. Morrison described Eetza gravel as predominantly well-rounded, boulder to cobble shoreline gravel, and he proposed that storm-generated winds necessary for transporting such large clasts were much greater during Eetza time than during the Sehoo lake phases. Morrison apparently used this as a criterion for differentiating his much coarser Eetza beach gravel deposits from finer grained (cobble to pebble gravel) Sehoo beach deposits. (see Morrison, 1964, Fig. 8). Morrison's hypothesis that the more bouldery clasts were moved and deposited along Eetza shorelines is plausible, however it is difficult to test due to the sparse radiometric ages on shoreline deposits. It is also reasonable to assume that even the most bouldery shoreline deposits of Eetza age would have undergone reworking during Sehoo time, and thus any such deposits might more simply be mapped as part of the Sehoo alloformation. Our mapping scheme thus differs from Morrison’s in that we generally mapped all beach gravels at or below the Sehoo highstand elevation

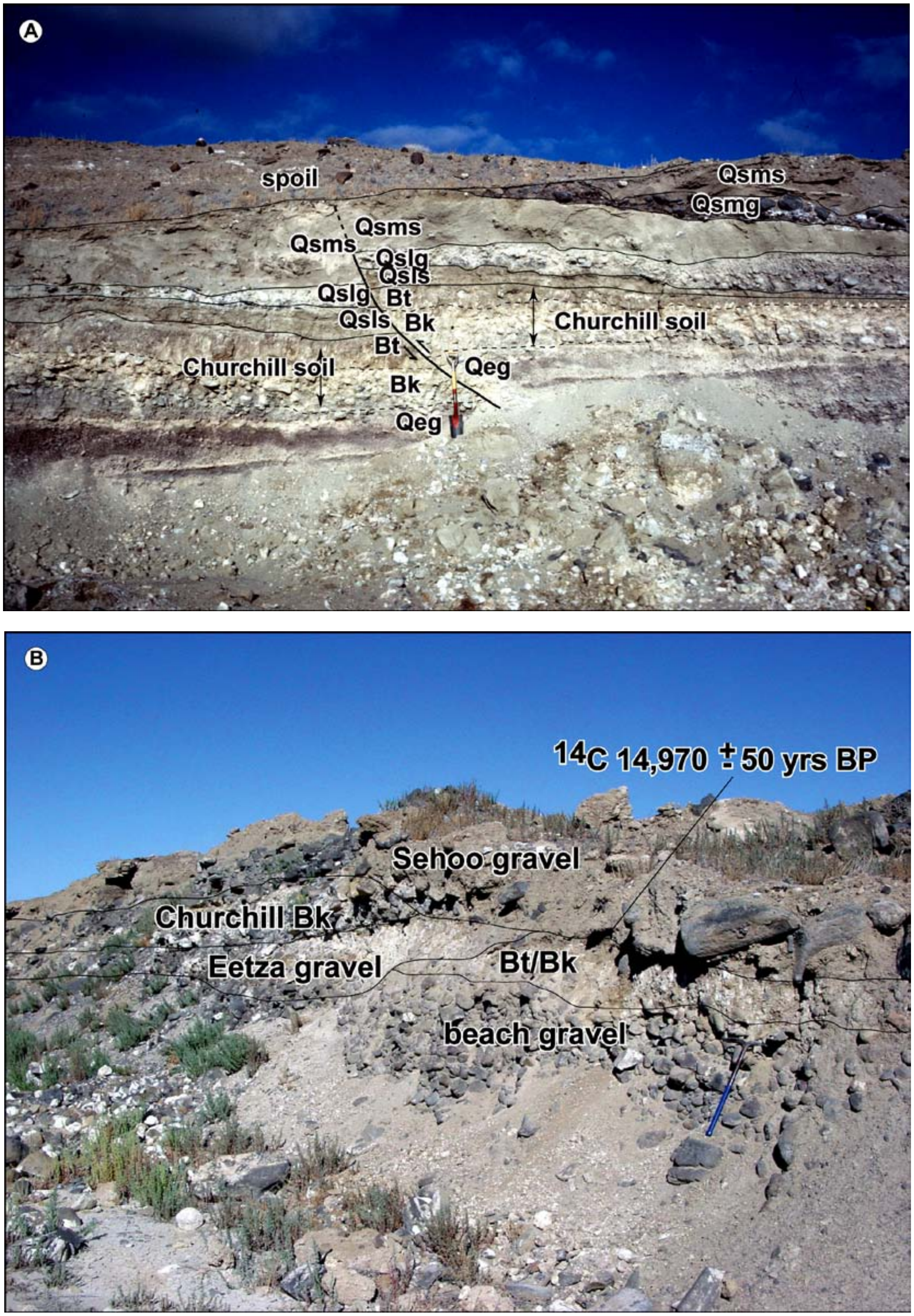

Figure 7. Exposures of Sehoo gravel-Churchill Geosol-Eetza gravel sections. **7A**. Gravel pit exposure (photo taken in 1980) at the mouth of Churchill Valley in western Wyemaha Valley showing Eetza through Sehoo stratigraphic relations as also shown in Morrison (1964, Fig. 15). Sections are now covered but showed the ½-m-thick argillic Churchill geosol separating Eetza and Sehoo beach gravel deposits with the section offset by an apparent reverse fault. Qeg: Eetza gravel; Qsls, Qslg, lower Sehoo sand and gravel; Qsms, Qsmg, middle Sehoo sand and gravel. **7B**. Trench exposure on hillslope about 30 m above 7A. A stage III Bk carbonate horizon below middle Sehoo gravel is interpreted to be the Churchill geosol developed in Eetza gravel; a lower Churchill-like Bt/Bk soil is interpreted to be the Cocoon geosol developed in beach gravel possibly correlative to the Rye Patch alloformation (Morrison, 1991). A snail shell from the base of the middle Sehoo beach gravel yielded a ^{14}C age of 14,970 ± 50 ^{14}C yr BP (Table 1, sample ^{14}C 20).

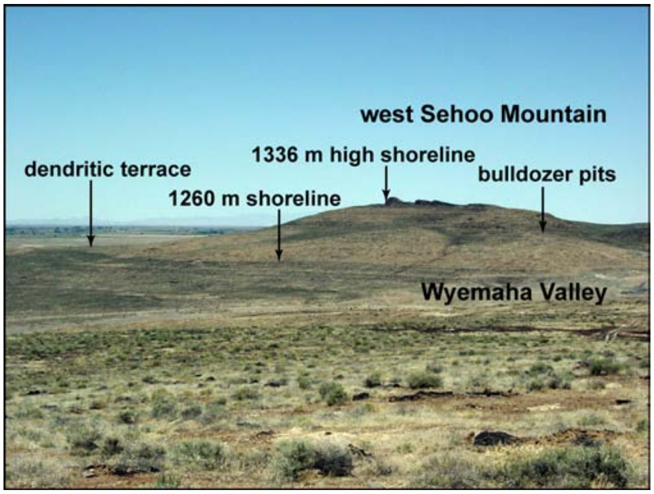

Figure 8. View looking north across Wyemaha Valley at the western part of Sehoo Mountain. The middle Sehoo dendritic terrace is a prominent tufa-covered bench at 1250–1270 m on the south and western flanks of Sehoo Mountain. Bulldozer pits are location of exposure shown in Figure 7A.

(~1336 m) as Sehoo age deposits, allowing for the possibility that Eetza gravel may be present beneath a thin veneer of Sehoo gravel. We mapped Eetza gravel only where clear relative age relations between Eetza and Sehoo deposits could be established. These locations are limited to areas at or near the highstand shoreline elevations for the two lake cycles, which appear to be approximately equal in the Lahontan and White Throne Mountains areas.

Morrison (1964) believed that the highest Eetza shoreline was at an elevation of 1334–1336 m, about 3 m above the subsequent high shoreline of Sehoo time (1333 m). This interpretation was based on geomorphic and soils evidence reported at Eetza Mountain (Grimes Point quadrangle) and at Russell Spit about 16 km southwest of the study area (Fig. 1). In contrast, Adams and Wesnousky (1999) concluded on the basis of soils and surface morphology that the highest shoreline in the Lahontan basin is of Sehoo age and that the highest Eetza shoreline is located several meters lower, in agreement with the original interpretations of Russell (1885) who termed it the lithoid terrace.

In this study, we have examined the key locations of Morrison's (1964) Sehoo and Eetza shorelines, and we believe that Morrison's relative positions for these high shorelines are correct, although the absolute elevation differences are variable with the Eetza shorelines occurring at or slightly above the high Sehoo shorelines. At Russell Spit, there is convincing soil and morphologic evidence for higher pre-Sehoo shorelines; high Sehoo shoreline elevations range from 1330 to 1333 m, while the Eetza shorelines occur at 1334–1335 m elevation. In the Lahontan Mountains, the Sehoo high shoreline reached the same elevations as the Eetza high shoreline creating difficulty in differentiating the two deposits. On Eetza Mountain, for example, the high Sehoo shoreline gravels veneer the older high Eetza beach gravels at an elevation of 1336 m, a relation revealed only through evaluation of several soil pits excavated into the highest shoreline deposits. On Sehoo Mountain, we obtained a ^{14}C age of 12,240±70 yr BP[1] on the lithoid tufa terrace at 1330 m (Table 1, sample ^{14}C 13); this age suggests that the terrace is of Sehoo age, although we cannot rule out that it was also occupied during Eetza time.

Sehoo Alloformation (Qsl, Qsm, Qsu)

The Sehoo alloformation is associated with the last major lacustral cycle of Lake Lahontan, and it is the most widely exposed unit of the Lake Lahontan allogroup in the Lahontan Mountains. The unit was originally called the upper lacustral clays by Russell (1885); Morrison (1964; 1991) subsequently recognized three members of the Sehoo alloformation— lower, middle, and upper— but he did not differentiate them in his mapping of the Lahontan Mountains. Numerous radiocarbon ages from the Sehoo alloformation throughout the Lahontan basin in the western Nevada region are between 11–35 ka (cf., Broecker and Orr, 1958; Broecker and Kaufman, 1965; Benson and Thompson, 1987; Benson et al., 1990).

The lower Sehoo member (Qsl) records the rise of the last major lacustral cycle of late Pleistocene Lake Lahontan. Lower Sehoo beach gravel is exposed in a gravel pit at the south end of Churchill Valley (1265 m elevation), which contained snail shells dated at 38,320 ± 750 yr BP (Table 1, sample ^{14}C 23). Just southeast of the quadrangle, lower Sehoo beach gravels are exposed in a gravel pit where they contain the Wono tephra bed at an elevation of 1202 m. The age of the Wono bed in the Lahontan basin was placed at 27 ka by Benson et al. (1997), significantly younger than this Qsl radiocarbon date and other similar Qsl ages in the Pyramid Lake basin (Bell et al., 2005). At the north end of Rainbow Mountain the 27.6–31.9 ka Wilson Creek bed 15 tephra is within deep water lacustrine clay beds at an elevation of 1198 m (Caskey et al., 2004).

Middle Sehoo deposits (termed the Dendritic member by Morrison, 1964) are the most extensively exposed of the Sehoo alloformation, and they consist of several mapped subdivisions. A fine-grained, predominantly deep-water unit (Qsm) consists of silt, clay, fine sand, and mud with minor amounts of undifferentiated shallow-water beach sand and gravel, and it underlies all of the basins surrounding the Lahontan Mountains. Shallow water beach gravels (Qsmb) occur on the hillslopes where they are commonly associated with shoreline scarps. A prominent, broad, shoreline platform containing large (>1 m) dendritic

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[1] All radiocarbon ages are reported as uncorrected yr BP; see Table 1 for calendar corrected cal yr BP ages.

tufa heads at an elevation of 1250–1270 m (Fig. 8) represents a lengthy still-stand of the lake as it rose, and it is differentiated here as the Middle Sehoo dendritic tufa member (Qsmd). Similar dendritic tufa deposits blanket many of the shorelines and bedrock hill slopes, and these have been mapped separately as middle Sehoo tufa (Qsmt) where the deposits are thick (>1/2 m) and continuous.

The age of the middle Sehoo highstand (~1336–1337 m in the Lahontan Mountains) is generally placed at ~13 ^{14}C yr BP (Morrison, 1991; Adams and Wesnousky, 1998, 1999). Broecker and Kaufman (1965) reported more than a dozen radiocarbon ages on shells and tufa from the Lahontan Mountains ranging between 11.2 and 13.6 ka. In this study, we dated similar samples from pre- and post-highstand deposits and obtained ages ranging between 12.4 and 14.9 ka (Table 1). The middle Sehoo lake rose to 1270 m by 14.4–14.9 ka, and shell samples dated at 12.5–13.5 ka from the 1290–1300 m elevation suggest that these shorelines were occupied during both the ascending and recessional phases of the middle Sehoo lake.

Following the highest middle Sehoo lake stand at ~13 ka, the recession of Lake Lahontan occurred rapidly, possibly within 1 ky following the highstand, with the lake receding to near-desiccation at an elevation at least as low as 1190 m in the Carson Desert area (Morrison, 1991). This post-middle Sehoo recession was followed by a final lake rise in latest Pleistocene-early Holocene time, and deposits associated with this last lacustral phase of Lake Lahontan are part of the upper Sehoo member. Upper Sehoo deposits are best exposed between northern Sehoo and Rainbow Mountains where they consist of thin-bedded silt and mud capped by a distinctive thin, platy tufa. Near Fish Cave on the northwest flank of Sehoo Mountain, upper Sehoo deposits clearly lap up onto older middle Sehoo shorelines and tufa-covered beach deposits (Fig. 9). At higher elevations, upper Sehoo beach berms consisting of sand and small pebble gravel mark the maximum extent of the lake rise, which Morrison (1964) termed the S3 shoreline. These shorelines are difficult to differentiate from the older middle Sehoo recessional shorelines at most locations because of the similar shoreline morphologies, and the upper Sehoo beach berms can be recognized only by cross-cutting shoreline relations. For example, on the east flank of Rainbow Mountain near Rainbow Canyon (Fig. 10), a prominent beach berm at 1228 m lies at an oblique angle to middle Sehoo recessional shorelines and thus is clearly of upper Sehoo age. The 1228 m shoreline also crosscuts a fault scarp cut into middle Sehoo shoreline deposits; the 1228 m beach berm is cut only by the historical 1954 scarps that formed in this area. Based on similar crosscutting shoreline relations found in the White Throne Wash area southwest of the study area (Fig. 1), the upper Sehoo shorelines occur as high as 1232 m, so we have mapped upper Sehoo beach deposits to this elevation in the Lahontan Mountains.

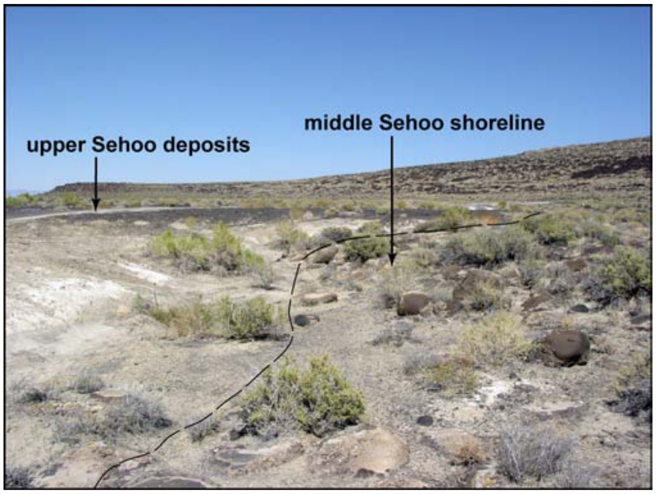

Figure 9. Upper Sehoo silt and sand deposits lapping onto Qsmb tufa-coated boulder deposits at an elevation of 1210 m along the north flank of Sehoo Mountain.

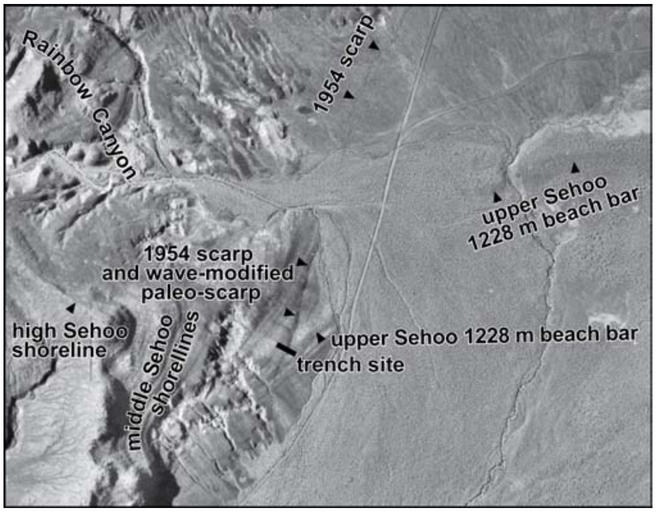

Figure 10. Low-sun-angle aerial photograph showing crosscutting Sehoo shorelines near Rainbow Canyon on the east flank of Rainbow Mountain. An upper Sehoo beach bar lies oblique to recessional middle Sehoo shorelines at an elevation of 1228 m. A fault scarp which pre-dates the upper Sehoo bar lies along one of the middle Sehoo strandlines and was reactivated in 1954. Paleoseismic trenching studies were conducted earlier at this site and are described in Caskey et al. (2004).

The age of the upper Sehoo member is not well constrained. Morrison (1991) placed the age of the deposits at ~8–9 ka based on two tufa dates from the Carson Desert and indirect evidence from Pyramid Lake. Adams et al. (2008) summarize additional age data and conclude that upper Sehoo deposits in the greater Lahontan basin were associated with the Younger Dryas climatic event at ~10.5 ka. In this study, we dated multiple samples from upper Sehoo deposits, most of which produced anomalously old ages in the range of 13–38 ka indicating that the samples were reworked from older deposits

(Table 1). We believe that the best age constraint for the upper Sehoo 1228 m shoreline comes from a charcoal sample collected from beach sand at the base of the 1228 m gravel bar exposed in a paleoseimic trench excavation (Fig. 8). This charcoal sample yielded an age of 9950 ± 60 ^{14}C yr BP (Table 1, sample ^{14}C 11) providing a maximum limiting age for the 1228 m shoreline (Caskey et al., 2004).

Fallon Alloformation (Qfs)

Following the recession of the upper Sehoo lake in the early Holocene, the Carson Desert was filled by several smaller shallow lakes that alternated with periods of fluvial deposition of the Carson River and eolian activity on the basin floor. Morrison (1964, 1991) identified several successively lower lake stands that each desiccated, and he grouped these deposits in the Fallon Alloformation. The deposits are lithologically distinct from the older Sehoo deposits: they consist predominantly of poorly sorted silty sand and small pebble gravel; they locally contain one or more Mono Craters tephra beds; and they are rich in snail and mollusk shells. These shallow lake deposits are mapped as Qfs; eolian deposits of the Fallon alloformation are mapped separately as Qfe.

The highest of the Fallon lake stands (F1) was believed to have reached an elevation of 1202–1204 m, marked by a prominent beach berm on the south side of Eetza Mountain. Other principal Fallon shorelines mapped in the northern portion of the quadrangle occur at 1197–1198 m (F2) and at 1194–1995 m (F3, F4). Morrison (1991) placed the age of the highest Fallon lake F1 at ~4 ka based on correlation with a 3.7–3.8 ka archeological midden in Hidden Cave. Based on charcoal dates from the 1204-m beach berm south of Sehoo Mountain on the Grimes Point quadrangle (Fig. 1), Adams (2003) concluded that the age of the F1 lake was between 812 and 1000 ^{14}C yr BP. A sample of grass buried by the 1198 m F2 beach along the Wildcat Scarp (Fig. 1) was collected by J. Bell in 1980; Adams (2003) reported that the radiocarbon age of this grass sample was 1510±40 ^{14}C yr BP and interpreted the age to indicate that the 1198 m F2 lake was subsequently over-topped by a younger 1204 m F1 lake. A mollusk shell collected during this study from the 1204 m F1 deposit at the Wildcat Scarp yielded an older radiocarbon age of 1770±40 yr BP (Table 1, sample ^{14}C 2).

In the Grimes Point quadrangle, radiocarbon dates on mollusk and snail shells from Qfs deposits suggest that a series of lakes existed in the Carson Desert between ~1.5 and 3.9 ka. The ages of Fallon lake deposits exposed at the 1194–1195 m F3–F4 shoreline range between 1.5 and 1.9 ka, and radiocarbon dates on buried carbonaceous Qay$_1$ sediments (i.e., organic rich muds or, 'black mats') interbedded with Qfs sediment at these sites further suggest that at least two earlier lakes existed: one between 1.8 and 2.4 ka and one >3.9 ka (Fig. 11). Radiocarbon ages on surface shells from Qfs sediments in the Lahontan Mountains quadrangle are 2.1 and 3.6 ka (Table 1, samples ^{14}C 1, ^{14}C 2), consistent with the ages of the buried lake sediments.

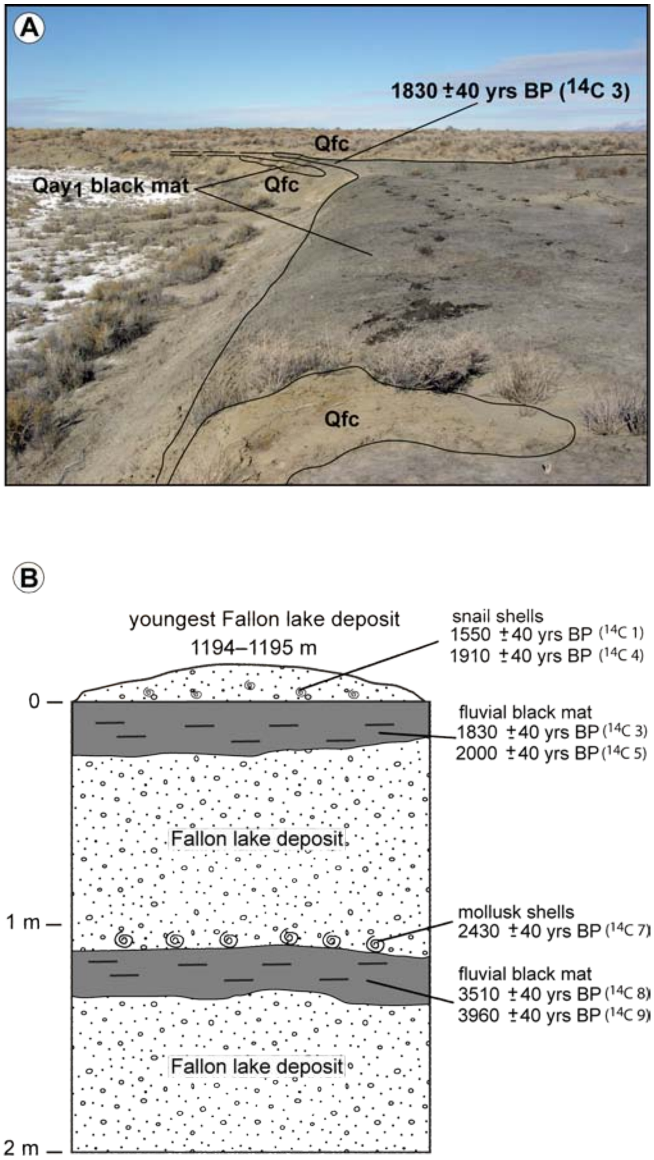

Figure 11. Interbedded Carson River fluvial floodplain/marsh deposits and Fallon-age lacustrine deposits with radiocarbon ages (Table 1). **11A.** Abandoned meander loop cut exposing carbonaceous fluvial deposits (Qay$_1$ black mats) interbedded with Fallon lake deposits (Qfs) in the Grimes Point slough just off the quadrangle to the west. Exhumed black mat dated at 1830 ± 40 yr BP. **11B.** Composite stratigraphic section with radiocarbon ages of alternating cycles of Fallon lake and Carson River floodplain (black mat) deposition exposed along meander bank cuts of the Grimes Point Slough and wash cuts near Macari Road in the Grimes Point quadrangle (see Fig. 1).

The Qfs deposits are underlain by the 6.85 ka (7.6 cal ka) Mazama tephra which is found in and near the Stillwater Point Reservoir diversion canal (Morrison, 1964; Davis, 1978). The Mazama tephra locality described by Morrison (1964, section 22a) was found, and a 5-cm-thick bed of Mazama tephra was encountered at a depth of 70 cm in an auger hole. The tephra bed occurs at the base of dark gray carbonaceous sediments overlying well-sorted brown sand. Morrison (1964) interpreted both units as lacustrine, but we believe the carbonaceous sediments overlying the ash bed are more similar to the Qay_1 black mat deposits of the Carson River floodplain, possibly a fluvial or marshy deltaic environment.

In summary, our findings suggest that a series of shallow Qfs lakes existed in the Carson Desert from about 1.5 ka to more than 3.9 ka following deposition of the 6.85 ka Mazama tephra. The lakes alternated with cycles of fluvial deposition by the Carson River which are marked by carbonaceous sediments associated with floodplain or marshy delta environments. The Qfs F1, F2, and F3/F4 shorelines of Morrison (1964) occur throughout the northern portion of the Lahontan Mountains quadrangle, however, they are best preserved along the Wildcat scarp (Fig. 1). The lake levels display topographic inset relations along the scarp indicating that each lake level was lower and stratigraphically younger. Radiocarbon dates from the Wildcat scarp suggest that the highest of the Fallon lakes reached the 1204 m F1 lake level at 1.7 ka. This age is older than that reported for the F1 shoreline by Adams (2003), but it is consistent with the 1.5 ka age obtained on the next lower 1198 m F2 lake level. At least two older lakes occupied the Carson Desert with one lake dated at between 1.8 ka and 2.4 ka and another occurring prior to ~3.9 ka. Neither of these older lakes apparently rose above the subsequent 1204 m F1 lake level.

Subaerial deposits

Wyemaha Alloformation (Qws)

The oldest subaerial deposits mapped in the Lahontan Mountains quadrangle are part of the Wyemaha Alloformation, the interlacustral subaerial unit stratigraphically separating the Eetza and Sehoo alloformations and containing the Churchill geosol (Morrison, 1964, 1991). Initially termed the medial gravels by Russell (1885), the Wyemaha alloformation in this quadrangle consists predominantly of eolian sand derived from the stratigraphically older Eetza lake sediments with minor amounts of locally derived alluvial fan sand and gravel. The unit is best exposed at the type locale at the west end of Wyemaha Valley and in wash exposures between Eagles House and Sehoo Mountain. Morrison (1964) mapped extensive areas of Wyemaha deposits throughout the Lahontan Mountains, but we did not differentiate these deposits if we could not clearly establish their stratigraphic position relative to younger (post-Sehoo) eolian deposits.

The Churchill Geosol formed in Eetza- and Wyemaha-age deposits prior to the rise of the Sehoo lake. At the type locale in Churchill Valley (Morrison, 1964), the Churchill geosol is a thick cumulate soil consisting of multiple reddened B horizons and distributed pedogenic carbonate accumulations in upper Wyemaha sands. In general, the Churchill Geosol is most strongly developed on Eetza age deposits that were subaerially exposed throughout the Eetza-Sehoo interpluvial period. These are most typically buried paleosols that contain strongly developed argillic and lower calcic (e.g., Bt-Btk-Bk) horizons. The best exposures of the Churchill Geosol were previously found in the borrow pits at the mouth of Churchill Valley, and the only remaining similar exposure is in the trench previously noted (Fig. 5). On high-level Eetza beach bars, the Churchill geosols are typically partly stripped by erosion and contain reddened B horizons with pockets of remnant argillic (Bt) horizons and stage II (Bk) carbonate horizons.

Alluvial fan and eolian deposits of Sehoo and younger age

Morrison (1964) distinguished a series of Sehoo and post-Sehoo age alluvial fan deposits and called them the Indian Lakes and Turupah alloformations. The Indian Lakes alloformation consists of cobble to boulder alluvial fan deposits that were deposited as the high middle Sehoo Lake was receding and during the subsequent rise of the late Sehoo Lake, and alluvial fans are found graded to different lake levels. The Turupah alloformation consists of eolian sand and alluvial fan deposits of post-Sehoo and pre-Fallon age on the basin floor, and Morrison (1991) placed the age of the unit at 5–8 ka.

In this study, the Qfy alluvial fan deposits correspond to the Indian Lakes alloformation but also include younger alluvial channel deposits. The oldest Qfy_1 deposits are alluvial fans graded to higher lake levels and exhibit darkly varnished, well pavemented alluvial surfaces, and the youngest Qfy_3 deposits post-date the late Sehoo lake and are graded to levels at or near the present basin floors.

We did not differentiate the Turupah alloformation because of stratigraphic uncertainties in the age of the deposits that Morrison (1964) mapped. Based on our mapping, the eolian and fluvial sand of the Turupah alloformation in the Lahontan Mountains and Grimes Point areas are Fallon age. Many of the eolian dunes contain Mono Craters tephra beds, including the type locale of the 1.5 ka Turupah Flat tephra near Salt Wells (Fig. 1; Davis, 1978). Transverse dune complexes associated with the Fallon lake (Qfs) shorelines along the southern and northwestern margins of Eetza and Sehoo Mountains also were found in this study to contain Mono Craters tephra which are chemically indistinguishable and which range in age from ~0.5 to 2.5 ka (Bell and House, 2007). Based on these relations, it is not possible to differentiate Turupah-age eolian dunes from those of Fallon age, and we have mapped all dune deposits as part of the Fallon alloformation.

Fluvial deposits of the Carson River (Qay$_1$, Qay$_2$)

Prior to construction of the Lahontan dam, the Carson River flowed into the Carson Desert as a series of distributary channels fanning out from the main channel about 10 km west of Fallon. During the several Fallon lake cycles the river built deltas, and during the Fallon intralustral periods the river migrated across the Fallon lake sediments flowing at times southeastward into Carson Lake and at other times northeastward into the Carson Sink (Morrison, 1964). The bifurcation of the Carson River was first described by Russell (1885) who had talked to early settlers in Fallon and learned how the river's course had episodically been altered by floods. Prior to 1862, the northern course had been abandoned and the river flowed southeast into Carson Lake (Fig. 1). A slough, here termed the Grimes Point slough, carried water from Carson Lake north to the Stillwater slough and the Stillwater region of the Carson Sink. In 1862, a flood partly diverted the river into the abandoned channel to the north of Rattlesnake Hill, and the river flowed both to the north and to the south. In 1867 or 1869, another flood caused the northern arm of the river to change course creating a new channel through Fallon and connecting with the Grimes Point slough. This new channel, called the New River channel, initially connected with the slough near Grimes Point, and continued to flow northward through this new channel and other new distributary channels and sloughs into the Stillwater area. The Grimes Point and New River have been the most recently active channels and still carry water to the Stillwater area by way of the Stillwater slough.

Based on the repeated lake and fluvial black mat sections found in the Grimes Point quadrangle (Fig. 11), the pattern of distributary channel flow into Carson Lake and northward into Stillwater must have been similar during Fallon time in order to account for the widespread floodplain/marsh sedimentation. Morrison (1964) differentiated crosscutting channel relations that he associated with different Fallon intralacustral intervals. In the Lahontan Mountains quadrangle, the older abandoned channels are partially buried by eolian sand and younger Fallon lake sediments, so the stratigraphic relationship of these older channels cannot be clearly established. Therefore this older set of distributary channels has been collectively mapped as older river deposits Qay$_1$. The more recent historical (post-1862) channels have been differentiated on the map as the youngest Carson River fluvial deposits Qay$_2$.

STRUCTURAL GEOLOGY

The predominant structural features in the Lahontan Mountains are northeast-striking normal and perhaps normal-right-oblique faults and associated west-tilted fault blocks. Older Tertiary units (Trb, Trd, and Ts) are much more intensely faulted and tilted than the little-deformed and unconformably overlying late Tertiary basalt flows of Tb. However, tectonism in the area is considered active as evidenced by two large earthquakes that occurred in 1954 (i.e., the M_s6.3 July 6 Rainbow Mountain and M_s7.0 August 24 Stillwater earthquakes), both of which produced surface faulting along the eastern range front of Rainbow Mountain (Tocher, 1956; Doser, 1986; Caskey et al., 2004).

Faulting in the Rainbow Mountain area

The most prominent faults in the Rainbow Mountain area lie along the eastern escarpment of Rainbow Mountain (i.e., the Rainbow Mountain fault) and within the Rainbow Mountain block. The north-northeast-striking Rainbow Mountain fault is an east-dipping normal or normal-right-oblique fault that mainly juxtaposes the basalt of Rainbow Mountain in the footwall against Ts sediments in the hanging wall (Fig. 3). The Tertiary volcanic flows that make up the majority of the Rainbow Mountain block consistently dip moderately toward the west. To the north the Rainbow Mountain fault splays into a western and eastern trace, both of which down-drop Ts sediments to the east against Trb basalt flows to the west. The largest net displacement along the Rainbow Mountain fault appears to occur along the central part of the mountain. The approximate minimum stratigraphic throw across the fault in this area is greater than 200 m based on the combined estimated thicknesses of Trb and Trd which make up the footwall block.

A second prominent zone of northeast-striking faults cuts through the central part of Rainbow Mountain. This is a complex fault zone, which involves Trb, Trd, and Ts units. The fault zone consists of numerous strands, which are well exposed locally within the range, many of which exhibit prominent fault breccia and hydrothermal breccia, although individual strands are difficult to trace along strike over large distances. Hence, most of these fault traces were not mapped for simplicity. Slickensides on many of the fault strands express strong components of both lateral and dip slip (i.e., right-normal oblique slip). The amount of net displacement along this fault zone is difficult to estimate due to uncertainties in the amount of long-term lateral slip. However, the basal contact of Trd is vertically separated as much as 100 m locally across the fault zone.

Morrison (1964) mapped numerous northeast-striking faults within the Rainbow Mountain block, particularly within the southern part of the range. Although there appear to be numerous, discontinuous fault strands with minor displacement throughout the length of the Rainbow Mountain block, Morrison's (1964) mapping appears to over-represent the extent of significant, through-going fault traces within the Rainbow Mountain block.

The July and August, 1954 Rainbow Mountain and Stillwater earthquakes both ruptured the Rainbow Mountain fault, producing a generally discontinuous zone of fault scarps (Fig. 12). Measured vertical offsets along the zone of ruptures reach a maximum of about 0.8 m with average vertical offsets of about 0.2 m (Caskey et al., 2004). Evidence for a right-lateral component of slip included locally offset stream channels, left-stepping *en echelon* fault scarps, and a prominent mole track just south of Stillwater Point Reservoir (Caskey et al. 2004).

Figure 12. Surface ruptures produced by the 1954 Rainbow Mountain-Stillwater earthquakes.**12A**. Small (30 cm) vertical 1954 scarp; photograph was taken by Karl Steinbrugge in late (?) 1954 near the Rainbow Canyon trench location of Caskey et al. (2004). **12B.** Trace of ½-m-high 1954 scarp which is highlighted by shadow and lies along the trace of the east-dipping range-front fault bounding the east margin of Rainbow Mountain.

Paleoseismic data (Caskey et al., 2004; Bell et al., 2004) show that two surface rupturing earthquakes, in addition to the historic events, occurred along the Rainbow Mountain fault during the past 15 ka, and further demonstrate that this is clearly an active fault. However, Tertiary strata are exposed at or near the ground surface nearly everywhere along the extent of hanging wall block, generally forming a range-front pediment, which suggests the fault has generally been tectonically quiescent when evaluated over a longer Quaternary time frame. Large cumulative normal slip displacements during the Quaternary would tend to favor a thick accumulation of hanging wall colluvium. Although some erosion has likely occurred during the lake cycles, the lack of significant fault-derived colluvium suggests that the recent reactivation of the Rainbow Mountain fault may have followed a significant hiatus in activity along the fault, and the Rainbow Mountain fault is thus not regarded as a high slip rate fault.

Structures east of Rainbow Mountain

The full extent of faulting and associated deformation in pre-Tb-aged units east of Rainbow Mountain is uncertain due to poor exposures. Ts strata are exposed only locally throughout the area between Rainbow Mountain and Eagles House where they generally appear to represent a consistent, moderately west-dipping stratigraphic section. East of Eagles House, more complex structural relations are exposed in channel cuts where there are a number of northeast-striking faults, zones of travertine-hosted breccia (described above), and locally steep to subvertical Ts strata.

The rhyolite of Eagles House is cut by two notable northeast-striking faults ~200 m south of Eagles House. The more northerly striking fault projects along strike directly to a small channel cut exposure of QTs deposits ~1.3 km to the northeast, which also exposes several fault traces that exhibit the same strike as the projected fault trace.

The basalt flows of Tb are little deformed and no clear fault traces were observed within Tb. Flow layering within the basalt most commonly dips gently to the west. Clearly all of the significant long-term deformation in the Lahontan Mountains predates deposition of the late Tertiary basalts. However, these younger basalt flows do appear to reflect broad warping or tilting of the Lahontan Mountains area.

DESCRIPTION OF MAP UNITS

Quaternary deposits

Alluvial and fluvial deposits

Qfy Young alluvial fan deposits, undifferentiated Alluvial fan deposits of post-middle Sehoo highstand age; in part called the Indian Lakes alloformation by Morrison (1964, 1991). Silty, sandy pebble to cobble gravel; poorly sorted; angular to subangular clasts of locally derived volcanic bedrock and rounded to subrounded clasts of reworked beach gravel.

Qfy$_1$ Early to middle Holocene fan deposits graded to recessional shorelines as middle Sehoo lake receded, and to desiccated basin levels prior to upper Sehoo lake rise. Well pavemented and darkly varnished interfluvial surfaces.

Qfy$_2$ Middle to late Holocene fan deposits graded to desiccated basin levels following upper Sehoo lake recession. Remnant bar-and-channel morphology and darkly varnished interfluvial surfaces.

Qfy$_3$ Late Holocene fan and ephemeral wash deposits graded to Fallon lake levels and Fallon intralacustral basin levels; includes axial deposits of principal drainages flowing through Wyemaha Valley to the basin floor.

Qay$_1$, Qay$_2$ Distributary channel deposits of the Carson River Dark gray mud and silty sand in abandoned channels, meander belts, and fluvial marshes; Qay$_1$ deposits pre-date the most recent Fallon lakes, and Qay$_2$ deposits are historically recent channel deposits along the Grimes Point, New River, and Stillwater Sloughs.

Fallon Alloformation

Qfe Eolian sand Brown, well-sorted, medium sand and silty sand in dune complexes and mantling beach berms along Fallon lake shorelines; locally contains one or more Mono Craters tephra beds (Tm on map). Middle (?) to late Holocene age. In part mapped as the Turupah alloformation by Morrison (1964, 1991).

Qfs Shallow lake sediments Brown to gray-brown silty sand, sandy silt, fine sand, mud, and small pebble gravel; laminated to massive and blocky, locally cross-bedded. Snail and clam shells are very common; multiple lake deposits (not differentiated) are found interbedded with carbonaceous channel and floodplain deposits (Qay$_1$) in slough bank exposures. Middle to late Holocene age.

Qfb Beach bar deposits Gray-brown to brown sand and silty sand and small pebble gravel associated with weakly developed Fallon lake beach bars at and below 1202 m on the northern slopes of the Lahontan Mountains. Middle to late Holocene age.

Sehoo Alloformation

Qsu Upper Sehoo lacustrine deposits Brown to gray, medium to coarse sand, poorly sorted silty sand, silt, sandy mud, and small pebble gravel; contains thin (5–10 mm) platy tufa layers that locally form exhumed, armored surfaces. Associated with deep to shallow water deposition of multiple early Holocene lake levels rising to a maximum elevation of 1232 m. Exhibits on-lapping unconformity with middle Sehoo shorelines at 1210 m on north flank of Sehoo Mountain; contains prominent bed of whitish, rounded Tsp pumice pebbles forming a distinctive bench at 1204 m along the northern shoreline slopes between Sehoo and Rainbow mountains. Reworked snail and ostracode shells yielded anomalously old (>13 ka) radiocarbon ages. Soils contain 10 cm reddened Bw to weak Bt horizons.

Qsub Upper Sehoo beach bar deposits Brown medium gravelly sand and pebble gravel forming shorelines and beach bars between 1210–1232 m that locally cross-cut middle Sehoo recessional shorelines; in part mapped as the S3 shoreline by Morrison (1964).

Qsm Middle Sehoo lacustrine deposits Gray to brown silt, clay, mud, and sandy silt associated with deep-water deposits of middle Sehoo lakes, and medium beach sand, coarse pebbly sand, and small pebble gravel associated with shallow water deposition; consists of reworked reddened Qw sand and muddy sand throughout central Wyemaha Valley. Best deep-water clay exposures occur at the north end of Rainbow Mountain. Contains variable thicknesses of undifferentiated Qsmb pebble gravel deposits, and most hillslopes below an elevation of 1336 m contain unmapped veneers of Qsm. Soils on high middle Sehoo and recessional shorelines contain 10–30 cm Bw and 30 cm Bk stage I–II horizons. Tufa and snail shells are common throughout the unit, with a prominent horizon of snail shells at 1290 m elevation.

Qsmd Dendritic tufa member Prominent tufa-cemented pebble gravel beach platform at 1250–1270 m elevation; thick (>1 m) tufa blankets and large (2–3 m diameter) dendritic tufa heads and colonies.

Qsmb Middle Sehoo beach bar deposits Gray to gray-brown gravelly coarse sand and rounded pebble to cobble gravel, locally boulder gravel and reworked Qeg beach gravel; mapped where deposits form distinct beach bars and shorelines on bedrock hillslopes. Commonly cemented by dendritic or lithoid tufa.

Qsmt Middle Sehoo tufa deposits Deposits of blanket tufa and dendritic tufa head colonies thick enough (> 1m) to be differentiated from the Qsm deposits on bedrock hillslopes; most common on hillslopes surrounding Sehoo Mountain.

Qsl Lower Sehoo lacustrine deposits Interbedded gray, rounded, cobble beach gravel and light gray diatomaceous silt; locally tufa-cemented; primarily exposed in gravel pits at south end of Churchill Valley and west of Salt Wells.

Qslm Lower and middle Sehoo lacustrine deposits, undifferentiated Deep-water gray to gray-brown silt, clay, and mud at the north end of Rainbow Mountain. Thin bed of a 27.6–31.9 ka tephra (Twc on map) in lacustrine sediments along the 1954 fault scarp (Caskey et al., 2004) indicates that part or all of the sequence is early Sehoo age.

Wyemaha Alloformation

Qws Interlacustral subaerial deposit; in this quadrangle, dominantly a brown to red-brown medium sand, silty sand, and sandy silt derived from eolian reworking of Qe deposits; locally a sandy fan gravel. Extensively underlies Wyemaha Valley but exposed primarily in deeper wash cuts and gravel pits. Contains the Churchill geosol; in buried exposures, soil consists of 30–60 cm strong argillic Bt with subangular blocky structure and 30+ cm Bk stage II–III horizons; relict surface exposures of the soil have 10–20 cm of reddened Bw with remnant pockets of Bt and 20–30 cm Bk stage II horizons.

Eetza Alloformation

Qeg Beach gravel deposits Rounded to sub-rounded pebble to cobble gravel exposed in buried stratigraphic context beneath the Churchill Geosol; locally recognized as older beach deposits situated adjacent to highest middle Sehoo shoreline deposits (1336 m) on the east flank of Sehoo Mountain and on the top of Eetza Mountain, just off this quadrangle to the west.

Pre-Lahontan lacustrine deposits

Qpe Pre-Eetza lake sediments Light gray to greenish-gray mud and clay exposed in the lower portion of the Wyemaha Valley gravel pit at an elevation of 1236 m; contains a 1-cm-thick tephra bed of uncertain age.

Qpeg Pre-Eetza beach gravel Rounded to sub-rounded pebble to cobble gravel found on Salt Wells and Sehoo Mountains at elevations of 1345–1367 m; inferred to be older than Qeg.

QTs Older lacustrine and alluvial sediments Brown, coarse, thin-bedded sand, small pebble sand, and fanglomerate; cross bedded with local fluvial or lacustrine beds containing rounded pebbles and cobbles of Tsp; exposed in wash nickpoint midway between Eagles House and Rainbow Mountain. Contains two 5–10 mm thick tephra beds (Tu on map) of uncertain age cut by small displacement northeast-striking faults with apparent reverse offset.

Tertiary bedrock units

Tb Late Tertiary basalt flows Mostly aphanitic; locally porphyritic with phenocrysts of olivine and plagioclase, commonly vesicular; depositionally overlies Ts; includes olivine basalt flows locally interbedded with Ts at the north end of Rainbow Mountain. Mapped as the Quaternary-Tertiary Bunejug formation by Morrison (1964).

Ts Tertiary sediments Heterogeneous assemblage of red, brown, orange-brown, light gray to white claystone, siltstone, mudstone, sandstone, pebbly sandstone, fine-pebble conglomerate, tuffaceous sandstone and siltstone, lithic tuff, pumaceous tuff, diatomite, and minor limestone; locally highly silicified and liesegang banded (i.e., altered to wonderstone); depositionally overlies Trb, Trd (inferred), and Teh.

Tsb Olivine basalt flows interbedded within Ts.

Tsp Rhyolitic pyroclastic agglomerate consisting of coarse pumiceous blocks/bombs up to 40 cm in diameter.

Teh Rhyolite of Eagles House Porphyritic quartz-biotite-hornblende rhyolite; exhibits complex flow-layering, locally hydrothermally altered.

Trd Dacite of Rainbow Mountain Dacite flows (?) with local basal vitrophyre, conspicuous banding, moderately hydrothermally altered, depositionally overlies Trb.

Trb Basalt of Rainbow Mountain Basalt and/or andesite flows, mostly vesicular, extensively hydrothermally altered, intruded throughout by less-altered basaltic sills and dikes (only some of which are shown on map).

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Table 1. Radiocarbon and calibrated ages for samples from the Lahontan Mountains quadrangle.

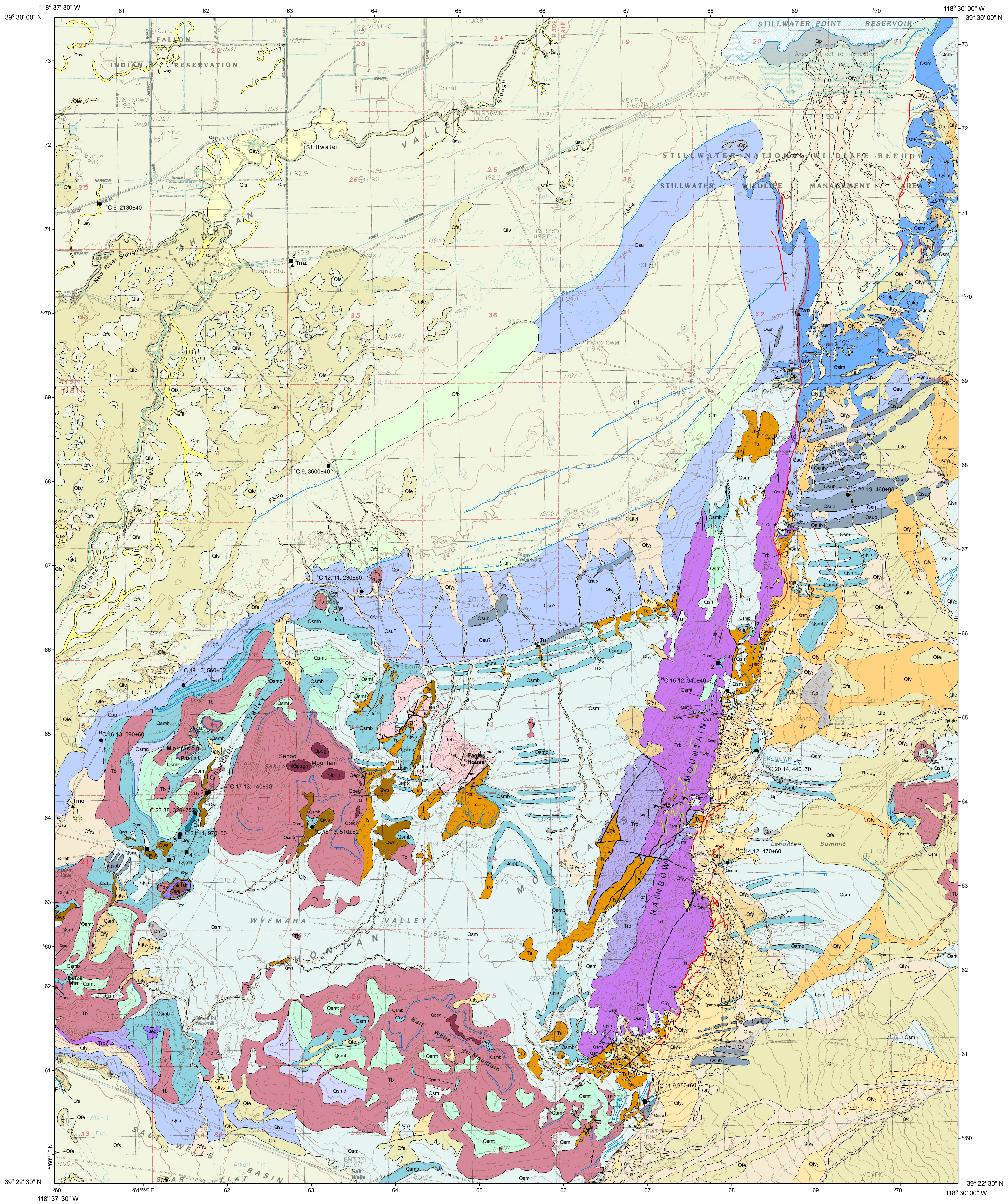
Sample No.	Lab No.	Material	^{14}C age (yr BP)	Calibrated age; 2 σ range; cal yr BP	Elevation (m)	Location (see geologic map and Fig. 1)	Unit
^{14}C 1	Beta-257495	snail shell	1550±40	1350–1530	1195	Grimes Point slough	Qfs
^{14}C 2	Beta-259941	mollusk shell	1770±40	1870–2040	1204	Wildcat scarp	Qfs
^{14}C 3	Beta-257494	carbonaceous sediment	1830±40	1640–1650	1194	Grimes Point slough	Qay$_1$
^{14}C 4	Beta-256298	snail shell	1910±40	1740–1940	1195	Macari Road section	Qfs
^{14}C 5	Beta-259940	carbonaceous sediment	2000±40	1870–2040	1194	Macari Road section	Qay$_1$
^{14}C 6	Beta-258558	snail shell	2130±40	2000–2240	1195	New River slough area	Qfs
^{14}C 7	Beta-256297	mollusk shell	2430±40	2350–2620	1194	Macari Road section	Qfs
^{14}C 8	Beta-256296	carbonaceous sediment	3510±40	3690–3890	1194	Macari Road section	Qay$_1$
^{14}C 9	Beta-258556	snail shell	3600±40	3830–4060	1195	North of Sehoo Mt	Qfs
^{14}C 10	Beta-257493	carbonaceous sediment	3960±40	4290–4340	1194	Grimes Point slough	Qay$_1$
^{14}C 11	GX-81208	charcoal	9,950±60	11,232–11,549	1228	Rainbow Mt trench site	Qsu
^{14}C 12	Beta-233253	platy tufa	11,230±60	12,960–13,250	1205	North of Sehoo Mt	Qsu
^{14}C 13	Beta-249002	lithoid tufa	12,240±70	13,990–14,210	1330	Western Sehoo Mt	Qsm
^{14}C 14	Beta-233604	snail shell	12,470±60	14,160–14,980	1280	East flank of Rainbow Mt	Qsm
^{14}C 15	Beta-233255	snail shell	12,940±40	15,060–15,510	1300	East flank of Rainbow Mt	Qsm
^{14}C 16	Beta-233252	snail shell	13,090±60*	15,180–15,810	1205	Northwest flank of Sehoo Mt	Qsu
^{14}C 17	Beta-233251	snail shell	13,140±60	15,230–15,880	1275	Churchill Valley-Sehoo Mt	Qsm
^{14}C 18	Beta-231113	snail shell	13,510±50	15,760–16,930	1290	South flank of Sehoo Mt	Qsm
^{14}C 19	Beta-231114	snail shell	13,560±50*	15,840–16,460	1205	Northwest flank of Sehoo Mt	Qsu
^{14}C 20	Beta-233603	snail shell	14,440±70	16,880–17,810	1270	East flank of Rainbow Mt	Qsm
^{14}C 21	Beta-231112	snail shell	14,970±50	18,010–18,590	1270	South flank of Sehoo Mt	Qsm
^{14}C 22	Beta-233602	ostracodes	19,460±90*	22,660–23,670	1225	Northeast flank of Rainbow Mt	Qsu
^{14}C 23	Beta-233254	snail shell	38,320±750	NA	1265	Churchill Valley-Sehoo Mt	Qsl

* anomalously old age

Table 2. Points of interest in the Lahontan Mountains

Location	Description
1	Type locales of Sehoo and Wyemaha alloformations, W1/2, sec. 21, T18N R30E (Morrison, 1964).
2	Type locale of Churchill Geosol (Morrison, 1964).
3	Previous exposures of Sehoo Alloformation-Churchill Geosol-Eetza Alloformation sequence found in Wyemaha Valley gravel pits (Morrison, 1964, Fig. 15C).
4	Previous exposure of faulted Sehoo Alloformation-Churchill Geosol-Eetza Alloformation sequence found in Wyemaha Valley gravel pit (Fig. 7A).
5	Present bulldozer pits exposing Sehoo Alloformation-Churchill Geosol-Eetza Alloformation sequence and a pre-Eetza beach gravel and soil (Fig. 7B).
6	Wash cut exposure of buried Eetza Alloformation beach gravel containing the Churchill Geosol one meter below high Sehoo beach bar at 1333 m.
7	Trench location across the 1954 Rainbow Mountain fault (Caskey et al., 2004).
8	Mazama tephra locality (Morrison, 1964; Davis, 1978).

Prepared as part of the STATEMAP components of the National Cooperative Geologic Mapping Program in cooperation with the U.S. Geological Survey



GEOLOGIC MAP OF THE LAHONTAN MOUNTAINS QUADRANGLE, CHURCHILL COUNTY, NEVADA

John W. Bell, S. John Caskey, and P. Kyle House

2009

QUATERNARY DEPOSITS

Alluvial and fluvial river deposits

Qfy Young alluvial fan deposits, undifferentiated
- **Qfy_3** Young fan alluvium of late Holocene age
- **Qfy_2** Young fan alluvium of late to middle Holocene age
- **Qfy_1** Young fan alluvium of middle to early Holocene age

Qay_2 Recent distributary channel deposits of the Carson River
Qay_1 Young distributary channel deposits of the Carson River
Qp Ephemeral playa deposits

Fallon Alloformation

Qfe Aeolian sand of late to middle Holocene age
Qfs Shallow lake sediments of late to middle Holocene age
Qfb Beach deposits of late to middle Holocene age associated with Qfs sediments

Sehoo Alloformation

Qsu Lacustrine sediments of the upper Sehoo Alloformation
- **Qsub** Beach deposits associated with Qsu sediments

Qslm Lacustrine sediments of the lower and middle Sehoo Alloformation, undifferentiated
Qsm Lacustrine sediments of the middle Sehoo Alloformation
- **Qsmd** Dendritic tufa member of the middle Sehoo Alloformation
- **Qsmb** Tufa deposits of the middle Sehoo Alloformation
- **Qsmt** Tufa deposits of the middle Sehoo Alloformation

Qsl Lacustrine deposits of the lower Sehoo Alloformation

Wyemaha Alloformation

Qws Subaerial sand and alluvial fan deposits

Eetza Alloformation

Qeg Gravelly beach deposits of the Eetza Alloformation

Pre-Lahontan lacustrine deposits

Qpe Pre-Eetza lacustrine deposits
Qpeg Pre-Eetza gravelly beach deposits
QTs Older lacustrine and aluvial sediments

TERTIARY BEDROCK UNITS

Tb Olivine basalt flows
Ts (Tsb, Tsp) Ts, Tertiary sediments, undivided; Tsp, pumice deposits; Tsb. olivine basalt interbeds
Teh Eagles House rhyolite
Trd Dacite of Rainbow Mountain
Trb Basalt of Rainbow Mountain with basalt sill and dikes

See accompanying text for full unit descriptions and references for this map.

Symbology (per FGDC-STD-013-2006)

Contact Solid where certain and location accurate, long-dashed where approximate.

75

Normal fault Solid where certain and location accurate, long-dashed where approximate, short-dashed where inferred, dotted where concealed; queried if identity or existence uncertain. Ball on downthrown side, arrow showing bearing and plunge.

1954 Historical fault Solid where certain and location accurate, long-dashed where approximate, dotted where concealed.

Lacustrine scarp Solid where certain; F1, Fallon lake shoreline

High shoreline Solid where certain.

Strike and dip of bedding

41 Inclined

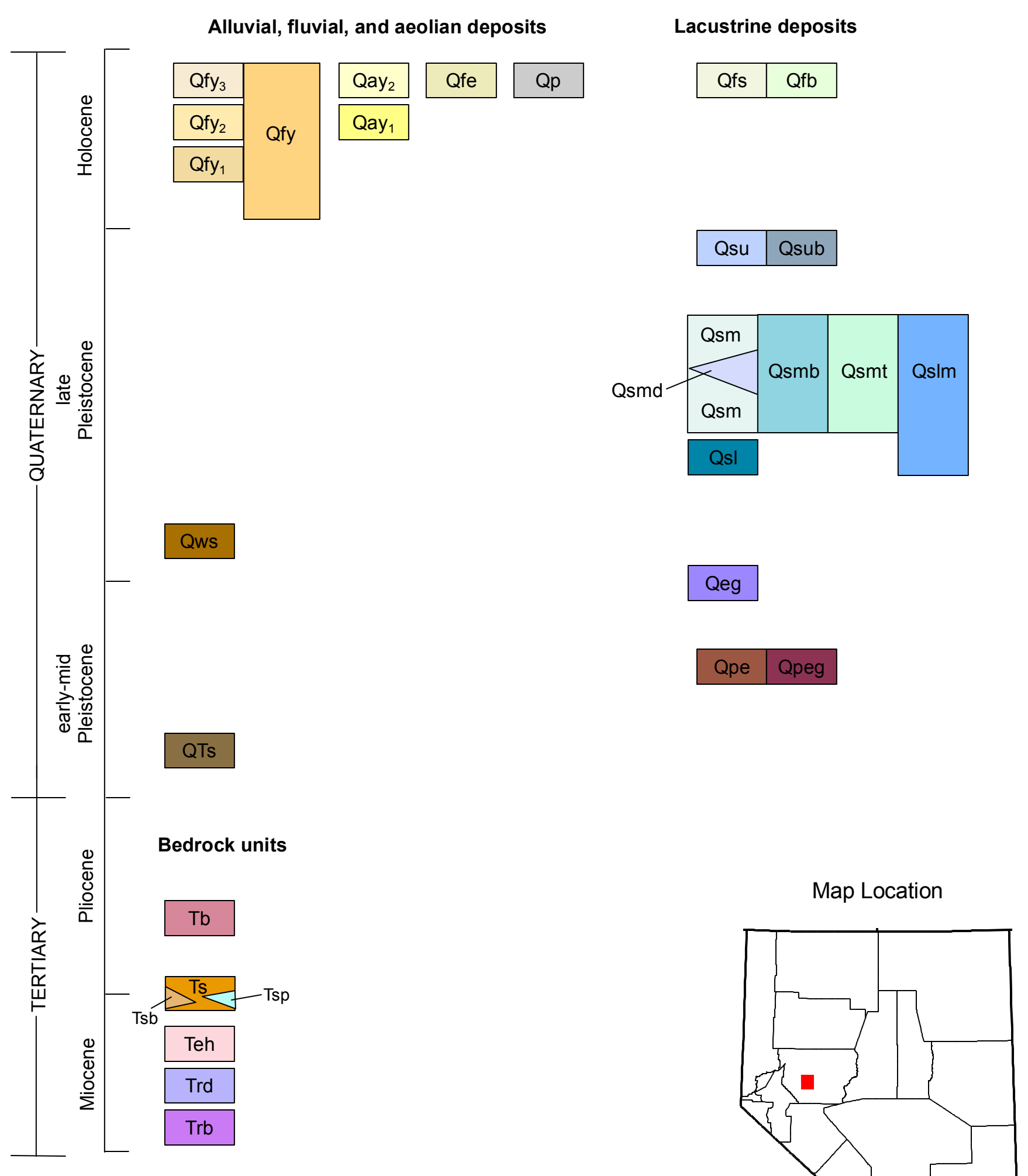
Strike and dip of flow banding or flow foliation in volcanic rocks

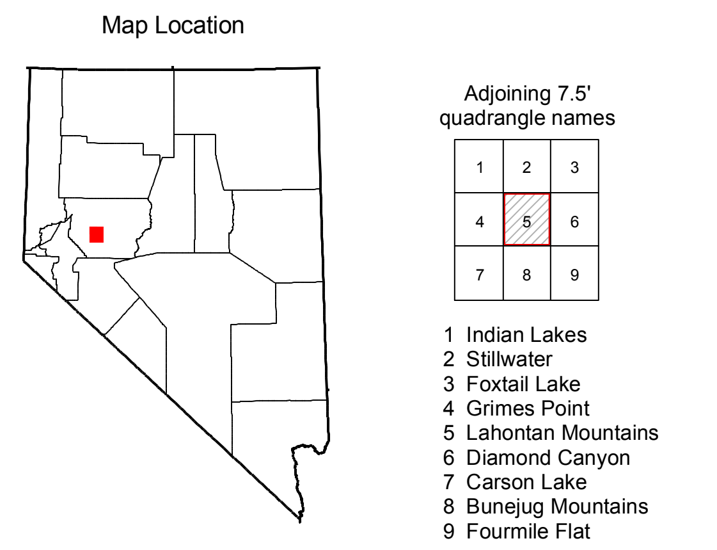
33 Inclined Vertical

▲ **Tephra locality**
Tmo, Mono Craters
Tmz, Mazama
Twc, Wilson Creek
Tu, uncertain

● ^{14}C00 **Radiocarbon sample locality** (see Table 1). Age is ^{14}C yr BP.

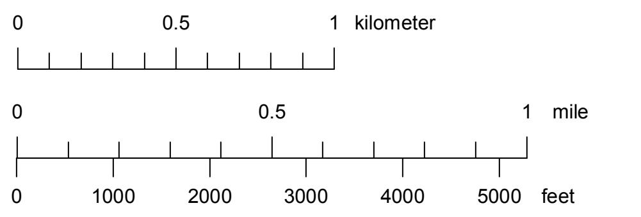
■ 1 **Point of interest** (see Table 2)





1 Indian Lakes
2 Stillwater
3 Foxtail Lake
4 Grimes Point
5 Lahontan Mountains
6 Diamond Canyon
7 Carson Lake
8 Bunejug Mountains
9 Fourmile Flat

Scale 1:24,000



CONTOUR INTERVAL 10 Meters

Projection: Universal Transverse Mercator, Zone 11,
North American Datum 1983 (m)

Base map: U.S. Geological Survey Lahontan Mountains
7.5' quadrangle (1985)

Nevada Bureau of Mines and Geology
Mackay School of Earth Sciences and Engineering
College of Science
University of Nevada, Reno

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Office and field review by Kenneth D. Adams, Nicholas H. Hinz, and Alan R. Ramelli

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2175 Raggio Pkwy.
Reno, Nevada 89512
ph. (775) 784-6691, ext. 2
www.nbmg.unr.edu; nbmgsales@unr.edu
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