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Geology Across and Under the Western Snake River Plain, Idaho: Owyhee Mountains to the Boise Foothills

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Geological Field Trips in Southern Idaho, Eastern Oregon, and Northern Nevada

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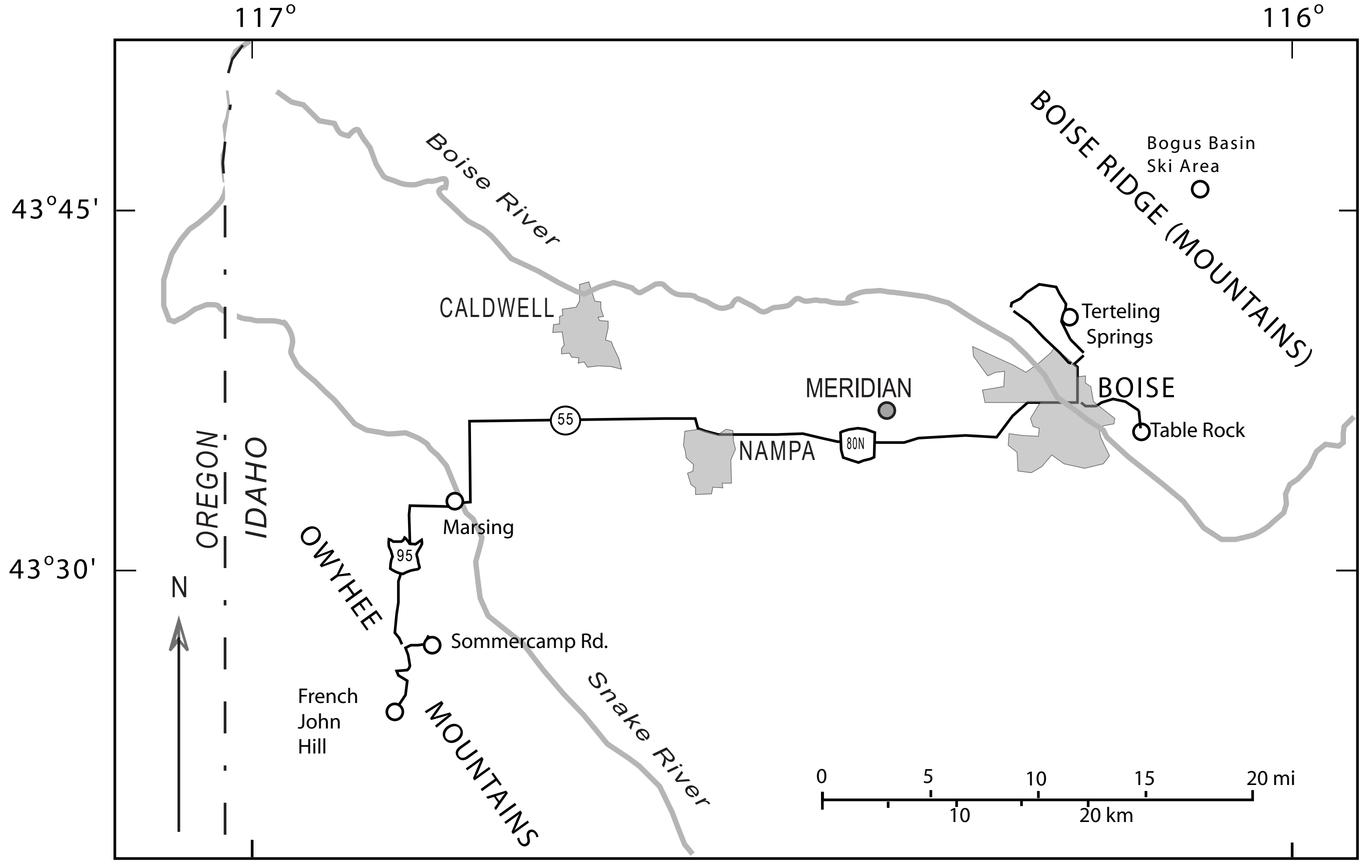

Figure 1. Field-trip route from Boise to the Owyhee Mountains and back to points of interest in the Boise foothills.

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Introduction

This 1-day field trip is a transect across the western Snake River Plain (fig. 1). The western plain is a continental-rift structure, 300 km long and 70 km wide. It is bounded and internally faulted by northwest-trending normal faults. The western Snake River Plain has a different orientation and structure than the eastern plain. The eastern plain is a curious downwarp related to magmatism and extension along the track of the Yellowstone hot spot (fig. 2). The faulted basin of the western plain began forming about 12 m.y. ago, and much of the relief was completed by 9 Ma. This timing corresponds with the passage of the hot spot located to the south about 11 Ma. Wood and Clemens (2002) suggest that softening of the lithosphere by the passing hot spot triggered extension and basin formation. The hot spot passage was accompanied by voluminous rhyolite volcanism to the south and by eruptions of rhyolite at or near the margins of the western plain (Bonnichsen and others, 2004; Perkins and Nash, 2002; Pierce and Morgan, 1992). Northwest of the western plain and in southeastern Oregon voluminous eruptions of the Columbia River and Steens Mountains flood basalts occurred between 16.1 and 15.0 Ma (Hooper and others, 2002a, 2002b; Camp and others, 2003). Earliest Columbia River basalts are as old as 17.5 Ma (Baksi, 2004)

Understanding of the sedimentary record builds upon earlier work in the central and southern part of the western plain by Malde and Powers (1962) who defined many of the stratigraphic units. Work of Squires (1992) improved our knowledge of the subsurface near Boise. The sediments record

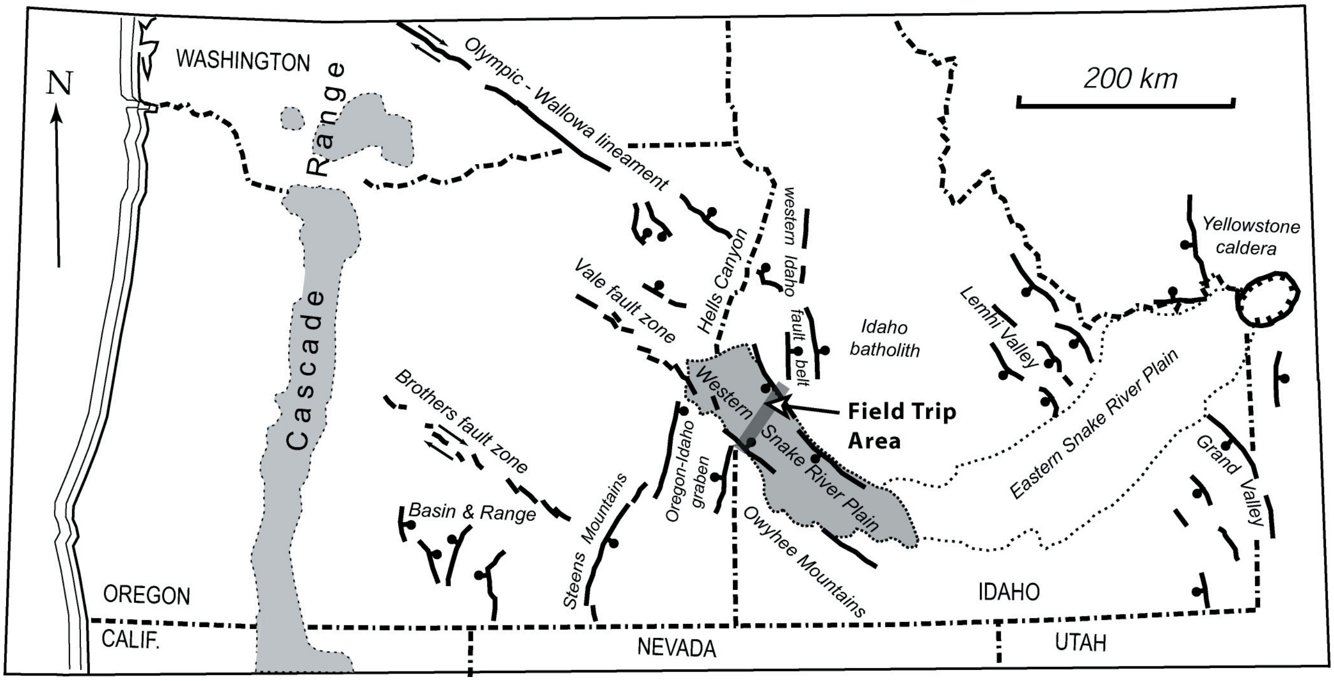

Figure 2. Western and eastern Snake River Plain and late Cenozoic geologic features of the northwestern United States. The western plain was a lake basin in the late Miocene to late Pliocene, usually referred to as "Lake Idaho" (after Wood and Clemens, 2002).

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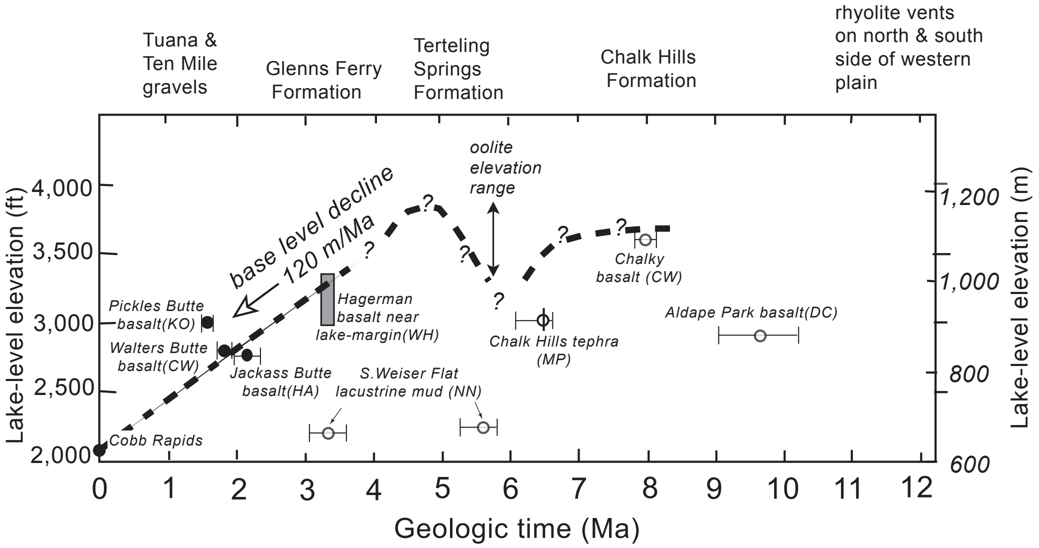

Figure 3. Plot of elevation of the lake deposits versus time. This plot does not take into account tectonic deformation that may have altered the elevation of lake deposits. Most localities are on the margin of the plain, which has not been so much affected by tectonic movement or compaction subsidence (Wood, 1994). Points on the graph are dates on lacustrine sediment, or basalt associated with or overlying the lacustrine section: K-Ar dates on basalt are: DC (Clemens and Wood, 1993), HA (Amini and others, 1984), Zircon fission-track ages on silicic ash are NN (Nancy Naeser, published in Thompson, 1991); $^{40}Ar/^{39}Ar$ ages on basalt are: CW (White and others, 2004), and KO (Othberg and others, 1995), WH (Hart and others, 1999), and tephrochronology from MP (Perkins and others, 1998).

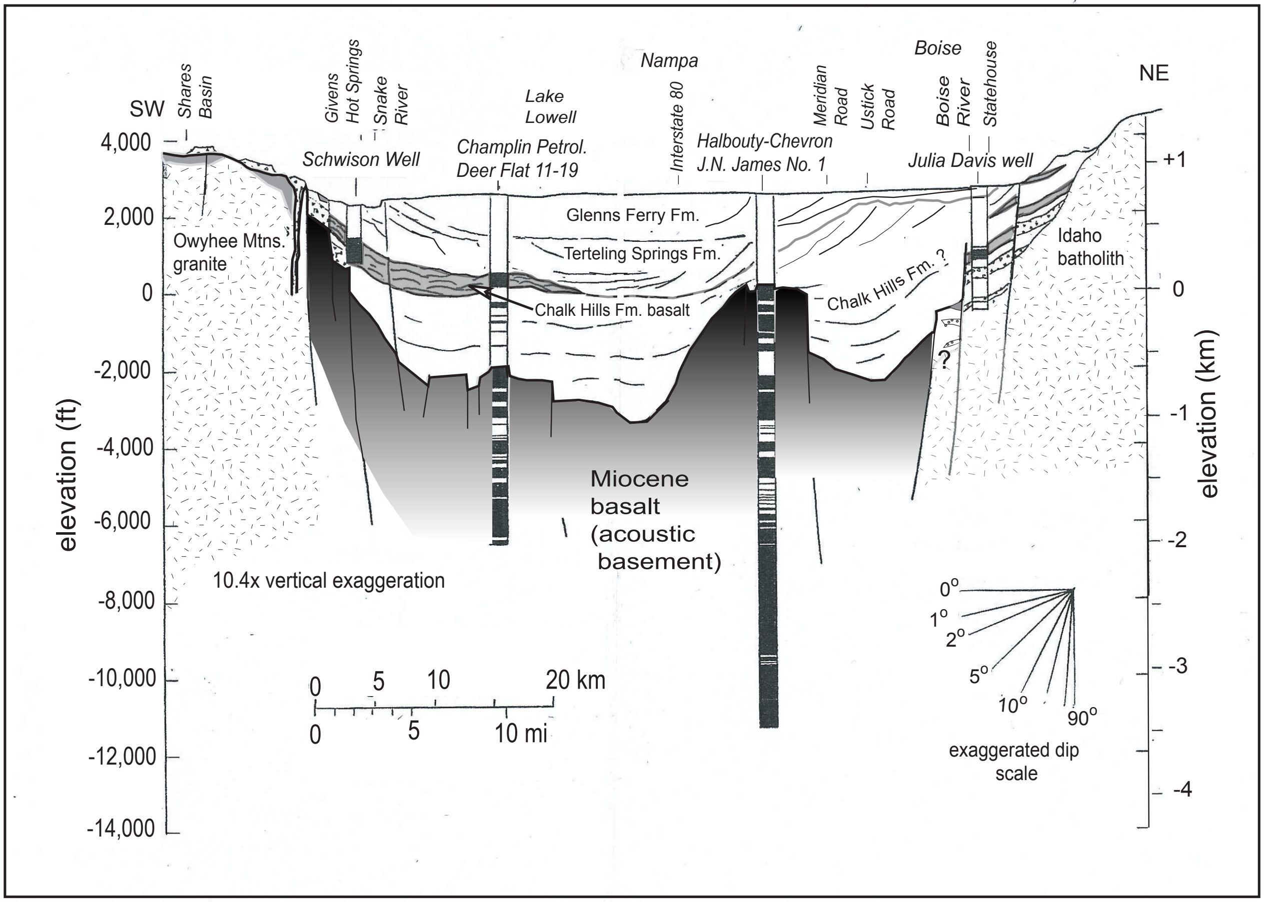

Figure 4. Section across the western plain showing major stratigraphic units, based upon seismic-reflection and well data. Dark patterns on well columns are basalt intervals: dotted pattern is rhyolite: no pattern is sediment.

two major episodes of large lakes that filled the basin (figs. 3 and 4). The Chalk Hills Formation records the first deposition of sand, lacustrine muds, and intercalated volcanics. Subsequently the level of the “Chalk Hills lake” declined, or perhaps the lake completely drained. Sediments and volcanics of the Chalk Hills Formation are deformed by tilting and faulting. The lake system then refilled and transgressed over eroded Chalk Hills Formation. The transgressive lake sediments grade upward and shoreward to calcareous muds and oolites; this sequence is called the Glenns Ferry Formation on the south side of the plain, and the Terteling Springs Formation on the north side (figs. 3 and 4). This last lake system is popularly known as “Lake Idaho”. The calcareous sediments indicate increased alkalinity of a lake within a closed basin. The lake then overtopped its spill point into ancestral Hells Canyon and, as it lowered, the drained basin filled with mostly sandy delta-plain units that are important aquifers.

The field trip starts in a rhyolite field in the Owyhee Mountains: the 11-Ma Jump Creek Rhyolite (fig. 5). We then look at the high gravels overlying the rhyolite at elevation 1,100 m. Descending onto the plain, we will examine the basal lacustrine sediments along Sommercamp Road, mapped as the Chalk Hills Formation. The lower Chalk Hills Formation contains numerous volcanic ash beds and an unusual pumice-block layer. Several basalt fields occur in the subsurface and in exposures along the margins. Along the Owyhee Mountains front, the transgressive sequence overlying the deformed and eroded Chalk Hills Formation is readily identified by an angular unconformity with a locally occurring ledge of nearly horizontal, brown, coarse, pebbly sandstone laying upon the

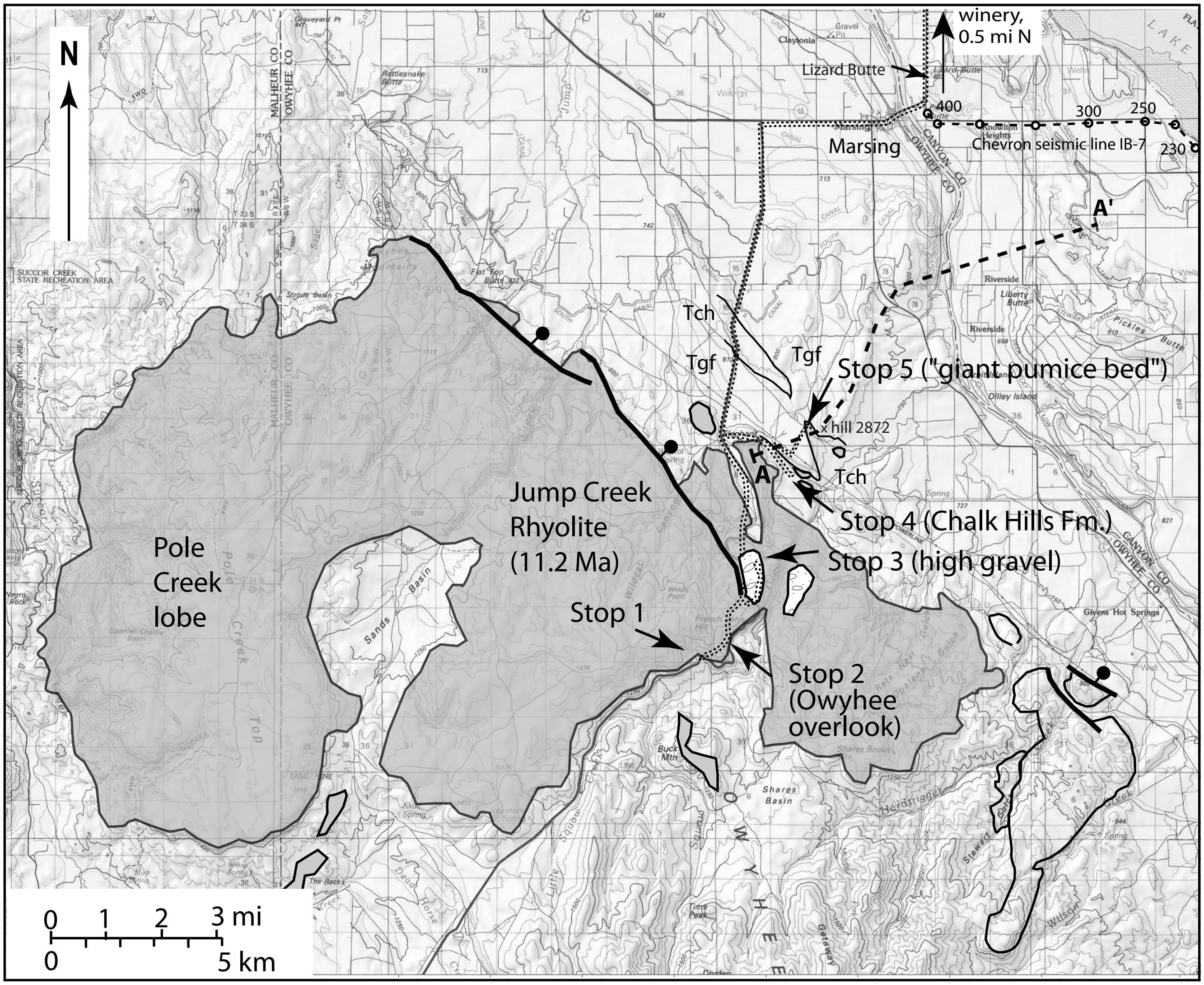

Figure 5. Map showing field-trip route along the Owyhee Mountains front near Marsing, Idaho, distribution of the 11-Ma Jump Creek Rhyolite, and associated geologic features along the edge of the western Snake River Plain. Location of cross-section A-A′ (fig. 16), seismic line (fig. 12), field-trip route (shaded line), and Stops 1-5 are shown.

tilted mudstone. This sandstone ledge is overlain by mudstone of the Glenns Ferry Formation.

Over most of the plain, we rely on seismic data and deep wells for information on the subsurface. From Marsing, we will drive across the plain through the towns of Nampa and Meridian to Boise. Squires and others (2003) describe a 15-km-long seismic line from Meridian to Boise from which we can interpret the episodes of lake filling and sedimentation as seen on the plain margins.

The angular unconformity between the Chalk Hills Formation and the Glenns Ferry Formation is not exposed along the Boise foothills; however, a section containing oolite bars is interpreted as the upper part of the transgressive sequence named the Terteling Springs Formation. Overlying the transgressive sequence is a massive Gilbert-style delta sequence of coarse sand that is interpreted as the response to regression of the lake after the lake overtopped the spill point at Hells Canyon. Downcutting of the outlet resulted in a slowly declining lake level and delta progradation over the basin. The basin filled and rivers flowed across the plain. Along the field-trip route, we observe valleys of the Snake and Boise Rivers that are incised about 150 m into the lake sediments.

FIELD-TRIP ROAD LOG

Mileages for this first leg of the trip are based upon the ***green milepost signs,*** *posted every mile on the northbound side of the highway.*

Mile-post	Inc.	
13.8	0.0	We travel north on U.S Highway 95 toward Boise. Starting point for mileage is at the south end of a large road cut at the crest of the highway at French John Hill, 14 mi south of Marsing, Idaho. Parking area is on the north side of highway, or continue south about 0.1 mi to large pullout on south side, where one can make a U-turn with good visibility.

Stop 1. Road Cut with Deformed Sediments and Pyroclastics at the Base of the Jump Creek Rhyolite, French John Hill, Owyhee Mountains

Road cuts here expose a jumble of rhyolite vitrophyre breccia and older sediments beneath the flow-banded and sheeted stoney rhyolite flows on the skyline (fig. 6). The Jump Creek Rhyolite covers 275 km^2 and is one of the younger rhyolites erupted along the margin of the western Snake River Plain (fig. 5). Neill (1975) obtained a K-Ar age of 11.2±0.2 Ma on sanidine. The rhyolite has many lobate flows, one upon another, and in this area is up to 250-m thick. Volume is estimated at 70 km^3. Bonnichsen and others (2004) consider this a rhyolite field made up of many segments. They report ^{40}Ar/^{39}Ar and K-Ar ages ranging from 10.6 to 11.7 Ma.

Rocks of the Jump Creek Rhyolite are identified by abundant (12–23 percent), conspicuous (up to 4 mm) phenocrysts of plagioclase. Sanidine and quartz vary in abundance up to 4 percent and are up to 2 mm in size. Microphenocrysts of ferrohypersthene and clinopyroxene are present (Ekren and others, 1981, 1982). A single analysis of this rock, on a water-free basis, shows 71 percent silica making it truly a rhyolite (analysis published in Ekren and others, 1984).

In the valley southeast of U.S. Highway 95, Squaw Creek has cut through the rhyolite into a 130-m-thick section of ashy stratified sediments mapped by Ekren and others (1981) as the Sucker Creek Formation. In the lower part of this section is an 8-m-thick, ledge-forming ash-flow tuff. The section rests upon 500 m of older Miocene basalt.

Directly beneath the rhyolite flow rock is about 20 m of dismembered silicic-ash beds and mud and ashy sediments, basalt breccia, beds of rounded stream gravels, and rhyolite

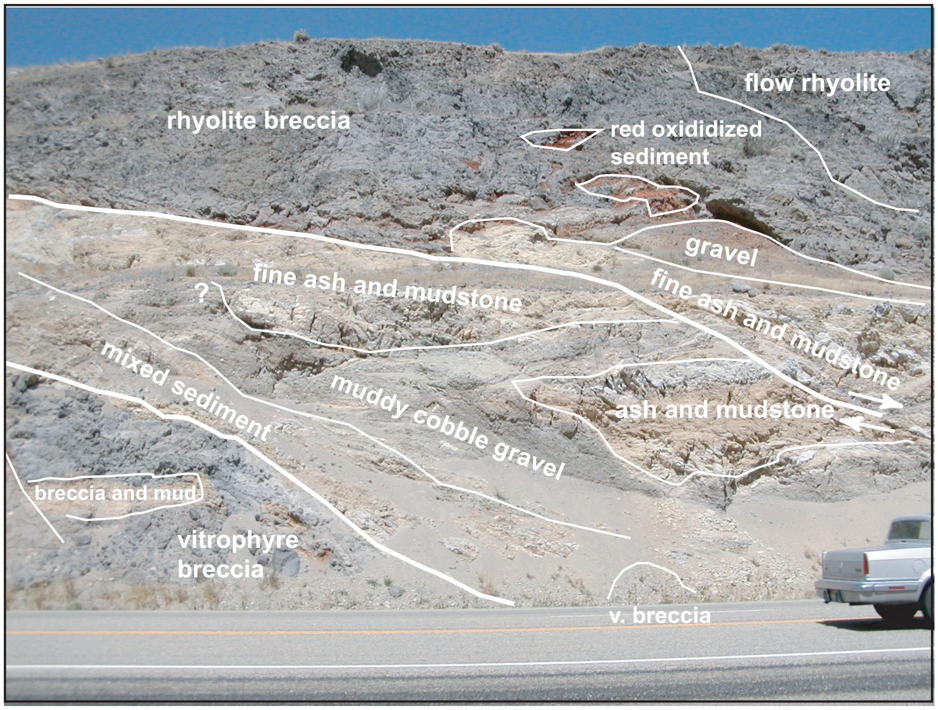

Figure 6. Deformed sediment and rhyolite at the base of the Jump Creek Rhyolite, Stop 1, west side of road cut on U.S Highway 95 (milepost 13.8).

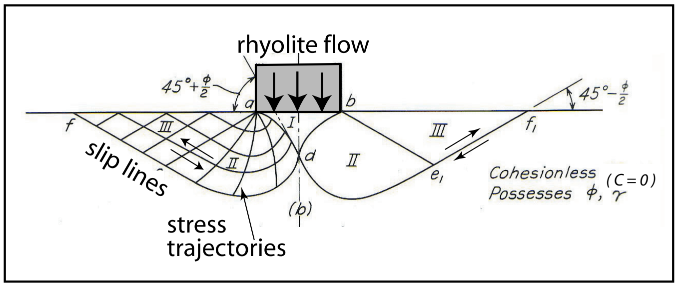

Figure 7. Diagram showing model of bearing-failure slip lines for fairly dense or stiff soil with frictional strength and no cohesion. This type of failure, with low-angle slip lines may have occurred as the thick flows of the Jump Creek Rhyolite piled up over wet sediments of the underlying Sucker Creek Formation (drawing after Terzaghi and Peck, 1967).

breccia. Such structural complexity originally suggested to me that this is a near-vent area of the rhyolite. Low-angle faulting cuts through the section exposed in the road cut which suggested sliding of near-vent volcanic topography (fig. 6). However, the low-angle faults are more likely analogous to bearing failures produced by loading the area with the thick rhyolite flows (fig. 7). The complex structures here are similar to larger scale features in the Absaroka volcanics described by Decker (1990) and which he attributed to liquefaction of saturated epiclastic and pyroclastic rocks in response to loading by lava flows. In this area, the overlying rhyolite lava was up to 200-m thick and imposition of such a great load over a short period of time (perhaps days to decades) could well have liquefied and deformed these materials.

Ekren and others (1984) suggested the Jump Creek Rhyolite may have been a rheomorphic tuff, but Bonnichsen and Kauffman (1987) have shown that thick breccias and features seen here are typical of large rhyolite flows. This area warrants a detailed description and study as few areas of the large hot-spot related rhyolite flows are so well exposed as here in Squaw Creek Canyon.

The older Miocene volcanic rocks of the Owyhee Range host major silver-gold deposits (*e.g.*, the Delamar Mine), about 30 mi due south of here (Halsor and others, 1988). The volcanic rocks rest upon Cretaceous (62 to 70 Ma) granitic rocks exposed at several places in the mountains southeast of here, which Taubeneck (1971) called the southern extension of the Idaho batholith.

Mile-post	Inc.	
		Walk north 0.5 km through the road cut to see the deformed sediments and rhyolite. Continue walking north, and the vans will be moved to the Owyhee Mountains Viewpoint, to pick you up.
14.1	0.3	Park for Stop 2.

Stop 2. Owyhee Country Viewpoint

Large parking area on the east side of road. The sign explains that the origin of the name "Owyhee" is not an Indian name as it would seem. It is an antiquated spelling of Hawaii, as used by Captain Cook. In 1819, Donald MacKenzie of the Canadian Northwest Company sent a group of trappers into these mountains. Among the party were several native Hawaiians who were never seen again, and so the mountains are named for those lost "Owyheeans".

The hill to the west of here is called French John Hill, named for "French" John Carrey who built a road in the early 1870s parallel to the present U.S. Highway 95 (Boone, 1988). From the view point, one looks across the deep rhyolite gorge of Squaw Creek and the north flank of the Owyhee Mountains to the western Snake River Plain. Across the plain are the Idaho batholith mountains north of Boise. Rimrock basalt along the north side of the Snake River Canyon overlies gravels, which are underlain by lake beds of the Pliocene Glenns Ferry Formation. Pickles Butte is a basalt vent area ^{40}Ar/^{39}Ar dated by Othberg (1994) at 1.58±0.085 Ma, which is the minimum age usually quoted for the complete withdrawal of Lake Idaho from this area. Basalts in this area, including Lizard Butte, are the westernmost extent of young basalt that overlies lakebeds.

About 14,500 yr ago, floodwaters of the Bonneville flood roared 60-m (200–ft) deep through the Snake River canyon below, but were confined to the canyon below 755-m (2,480-ft) elevation (O'Conner, 1993).

Mile-post	Inc.	
15.0	0.9	Turn east at milepost 15 on a paved road, that turns to gravel within 0.1 mi. Proceed for 0.3 mi, and continue straight at the Y to the old Highway 95 grade, and follow the abandoned highway north for a total of 1.1 mi from the turnoff at milepost 15. The road cuts are in the high gravel deposit of Stop 3.

Stop 3. High Gravels of the Owyhee Mountains and an Overlook of the Chalk Hills Formation-Glenns Ferry Formation Contact

From this abandoned grade of U.S. Highway 95, there is a good view over the western plain and the area of the next stop, Stop 4 (fig. 8). The road cuts are in an alluvial-fan gravel perched high in the Owyhee Mountains. Ekren and others (1981) mapped these high gravels (figs. 5 and 9) but did not comment on their significance. The gravels clearly overlie the Jump Creek Rhyolite, but their relationship to the lake deposits is unclear. The elevation here is 1,100 m (3,600 ft), which is the highest elevation of most lake deposits around the plain margin. It is likely this is an old alluvial fan sequence

Figure 8. Overlook of the western Snake River Plain, looking north from Stop 3.

that graded to Lake Idaho, but we do not know the age of the gravels or the amount of vertical faulting that displaced the gravel downward to the north. We will see a thinner, but very similar, gravel overlying the top of the Chalk Hills Formation in the Sommercamp Road cut at the next stop (see fig. 10).

The road is blocked at a distance of 1.3 mi, so turn around, park, examine the gravels and the view (fig. 8), and then return by the same route back to the new U.S. Highway 95.

Mile-post	Inc.	
15.0	1.1	Turn north toward Boise on U.S Highway 95 and proceed down the grade.
16.8	1.8	Road cut to the west side of the road exposes the contact between vitrophyre and overlying stoney rock of the Jump Creek Rhyolite. The vitrophyre contains abundant spherulites and stretched lithophysae. These features in the glassy part of the flow are attributed to pockets of higher vapor content that cause crystallization and devitrification emanating from the vapor-filled voids. These stoney-rhyolite spherulites form in the hot glass (Lofgren, 1971; Cas and Wright, 1988).
16.9	0.1	Road cut on west side of road exposes a northwest-trending fault, with a 1.5-m-thick fault breccia. Bentonitic claystone of the lower Chalk Hills Formation is faulted down to the northeast against the Jump Creek Rhyolite.
18.4	1.5	Turn east from Highway 95, just past the weigh station, on to Sommercamp Road. Travel east on Sommercamp Road for 0.9 mi to the top of the grade and road cut.

Figure 9. High gravels at Stop 3 (see fig. 5 for location). Mudstone overlain and interbedded with cross-bedded coarse sand and subangular gravel. Rock pick handle is 30 cm, for scale.

Stop 4. Chalk Hills Formation Along Sommercamp Road

We will walk down the grade and examine the road cut of deltaic sediments and then return to vans at the top of the grade on Sommercamp Road.

The Chalk Hills Formation represents sediments of the earliest large lake in the western Snake River Plain rift. The age of the formation is poorly constrained. In their review of radiometric ages on the formation, Wood and Clemens (2002) place its age between 10 and 6 Ma. The road cut along Sommercamp Road exposes a section of foreset and topset beds of a delta (fig. 10). These sediments are near the base of the formation and rest upon a section of clay-altered vitrophyre of the Jump Creek Rhyolite (fig. 11).

The delta sediments in the road cut are unconformably overlain by a gently-west-dipping, grey cobble gravel, similar to that seen at Stop 3. The gravel is faulted at the west end of

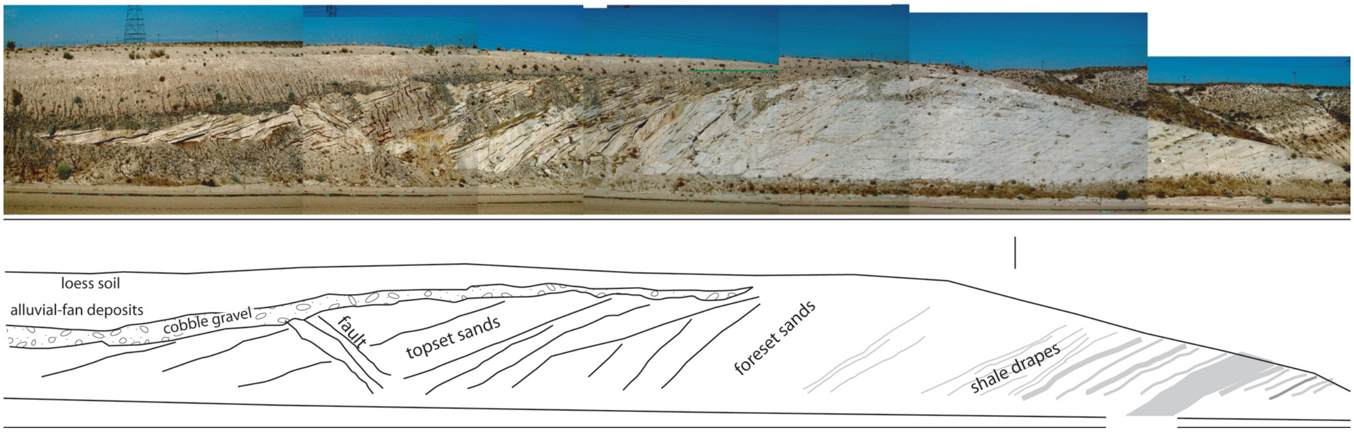

Figure 10. Delta foreset and topset beds of the Chalk Hills Formation along road cut of Sommercamp Road at Stop 4. The basalt ash marker bed in figure 11 is about 50 m west of photo along road cut.

the road cut and is overlain by unfaulted alluvial fan deposits and a loess soil. The Glenns Ferry Formation is missing in this road-cut exposure. One kilometer north of this road-cut exposure, 10 m of lacustrine sediment of the Glenns Ferry Formation unconformably overlies the Chalk Hills Formation with an angular discordance of about 8°.

The Chalk Hills Formation is about 110 m thick in this area (fig. 11). We will be looking at the sediment and volcanic features at two outcrop areas, here along Sommercamp Road, and another in a gulch 1.6 km (1.0 mi) northeast of here. The formation here is mostly claystone with an arkosic sandstone bed near the base, abundant intercalated silicic-ash layers, and delta sands that are mostly coarse silicic ash. Topset beds have well-preserved ripple marks. The foreset beds are mostly coarse sand ash with mud drapes, typically 0.1–0.5 m thick. Mud drapes form on the foreset sand beds in the time intervals between sand avalanche and deposition on the foreset slopes, or when a particular depositional delta lobe is temporarily abandoned by a distributary.

Exposed along Snake River Plain margins and also detected on seismic sections and wells beneath the plain, 10 km (6 mi) north of here (figs. 12 and 5) are intercalated local basalt fields within the Chalk Hills Formation. Many of these basalt fields erupted into water (Bonnichsen and others, 1997). At this locality, basalt occurs as one or two layers of scoriaceous ash and lapilli beds about 0.5-m thick at the west end of the road cut and indicated in the upper part of the stratigraphic section (fig. 11).

At the top of the Sommercamp Road grade, take the dirt road to the north through the barbed-wire gate and follow the track that parallels the power transmission line to the southeast. Travel 0.3 mi to a road that turns left (north) and follows the wooden-pole power line to the northeast. Travel 0.7 mi to the edge of the mesa and park.

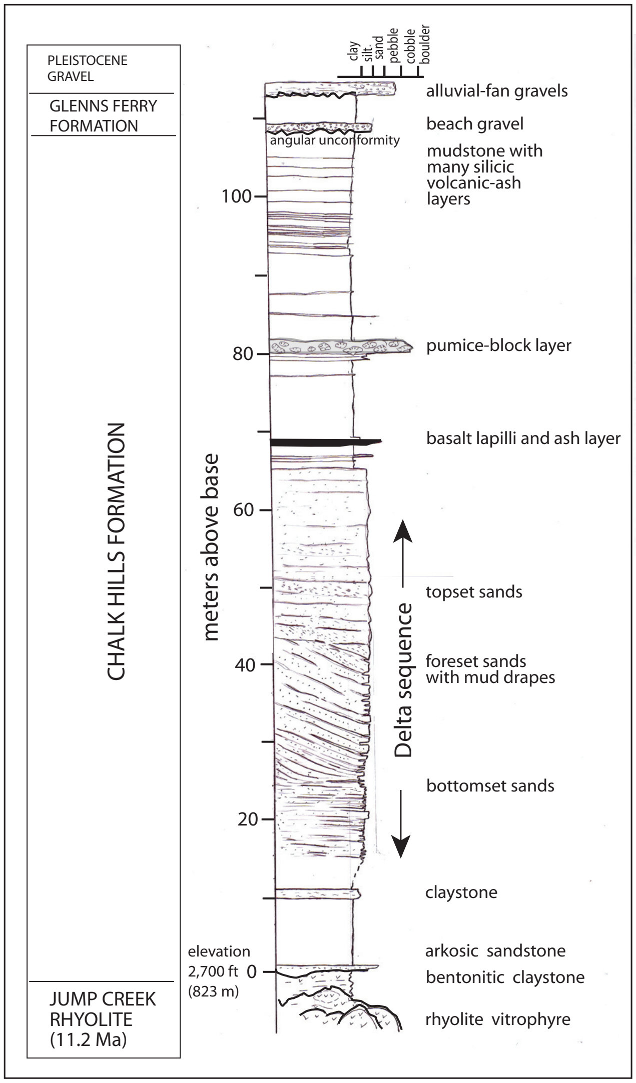

Figure 11. Graphic stratigraphic column of the Chalk Hills Formation at Stops 4 and 5.

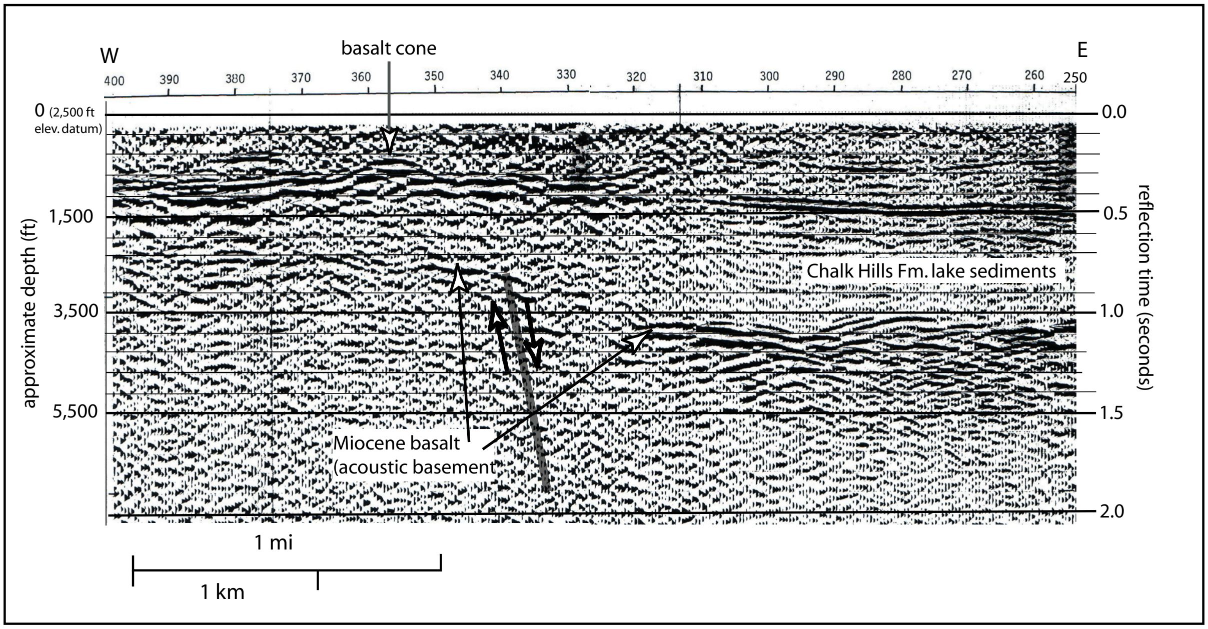

Figure 12. Seismic-reflection section showing a subsurface basalt field in the Chalk Hills Formation, between Marsing and Lake Lowell Reservoir (shotpoint locations shown on fig. 5, Chevron Seismic Line IB-7, shot points 250–400). The basalt field is 305–460 m (1,000–1,500 ft) below the surface. The top of the basalt appears as high-amplitude reflections from the sediment-basalt interface. The basalt field has relief due to cones with slopes of 23°. On the west end of the section, at a depth of 670 m (2,200 ft), is the surface of the older Miocene basalt beneath the Chalk Hills Formation. This older basalt surface is faulted down to the northeast to a depth of 1,070 m (3,500 ft,) or a displacement of 400 m (1,300 ft). Faulting of the basalt field within Chalk Hills Formation appears to be less than 90 m (300 ft).

Stop 5. Giant-Pumice Bed of a Sublacustrine Rhyolite-Dome Eruption Within the Chalk Hills Formation Sediments

There is a rough road over the rim and down to the valley below, on which we will walk 300 m northeast to exposures of the “giant-pumice bed”.

A remarkable layer of large (up to 1 m) pumice blocks, about 1.5-m thick, is exposed in a gulch in the SW quarter of section 32, T. 2 N., R. 5 E. The pumice blocks are radially fractured, but the broken pieces are intact, indicating they were deposited before they fractured (fig. 13). Post-deposition fractures indicate the blocks were still hot when emplaced and then cracked upon cooling. This unusual type of deposit also has been described at La Primavera Volcano, Mexico, by Clough and others (1982) and Cas and Wright (1988). The blocks are interpreted as pieces of the pumiceous carapace of a rhyolite dome that erupted beneath a lake and then floated and shoaled while still hot and intact (fig. 14). Also in this gulch, is the continuation of the section above the basalt ash seen in the road cut of Stop 4. Here the section contains many silicic volcanic ash layers within claystone, and is locally overlain by

Figure 13. Large fractured pumice block in pumice-block layer within the upper Chalk Hills Formation at Stop 5.

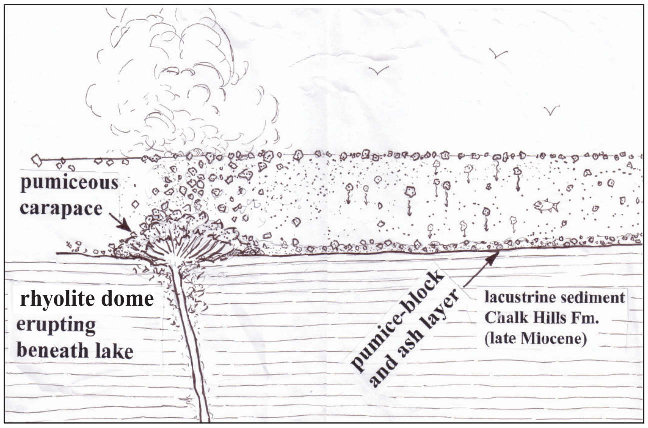

Figure 14. Sketch of a pumice dome eruption beneath the lake. It seems unlikely the large blocks waterlogged and sank, because they must have been hot and intact when emplaced. More than likely, the large blocks were steaming hot and still intact and then fractured in place upon further cooling.

a 1-m-thick horizontal ledge of pebbly sandstone and 10 m of massive lacustrine mudstone of the Glenns Ferry Formation (figs. 15 and 11).

The Glenns Ferry Formation dips a few degrees to the north, and the section is much thicker north of here (fig. 16). About 0.5 km (0.3 mi) south of this valley along the dirt road that climbs the north mesa is a sequence of silicic volcanic ashes, one of which is about 1-m thick and can be traced for several miles to the north (fig. 16). The lowest part of the Glenns Ferry Formation contains veins of selenite gypsum suggesting local lagoons along the lake shore that dried intermittently. However, none of the formation here is calcareous. It does become very calcareous in its upper part, about 3 km north of here (fig. 16). Much of the lacustrine mud in a 670-m (2,200-ft) deep well beneath Caldwell, 22 km north of here, is also calcareous (Wood, 1994).

Optional 0.25-mi walk is a 180 ft climb to the mesa to the east (hill 2872), for a good view and photo of the angular unconformity. In this valley, at the bottom of the mesa to the north is the contact of the Glenns Ferry Formation over the Chalk Hills Formation; however, the prominent rusty-colored sandy gravel visible on the south side of the valley is missing here. The lower 7 m of the Glenns Ferry Formation contains selenite gypsum veins (satin spar), and the 70-m-thick section here is a monotonous mudstone with several volcanic-ash beds.

Mile-post	Inc.	
		Return to vans at top of the south mesa and retrace the route back west to U.S. Highway 95.
18.4		Turn right (north) on to the new U.S. Highway 95.
19.8	1.4	The angular unconformity is in the road cut on the west side of the highway. A horizontal ledge of brownish-orange pebbly sandstone of the basal Glenns Ferry Formation overlies the slightly tilted claystone and ash layers of the Chalk Hills Formation.
24.0	4.2	Junction of U.S. Highway 95 and State Route 55. Turn right (east) on to State Route 55 toward Marsing.

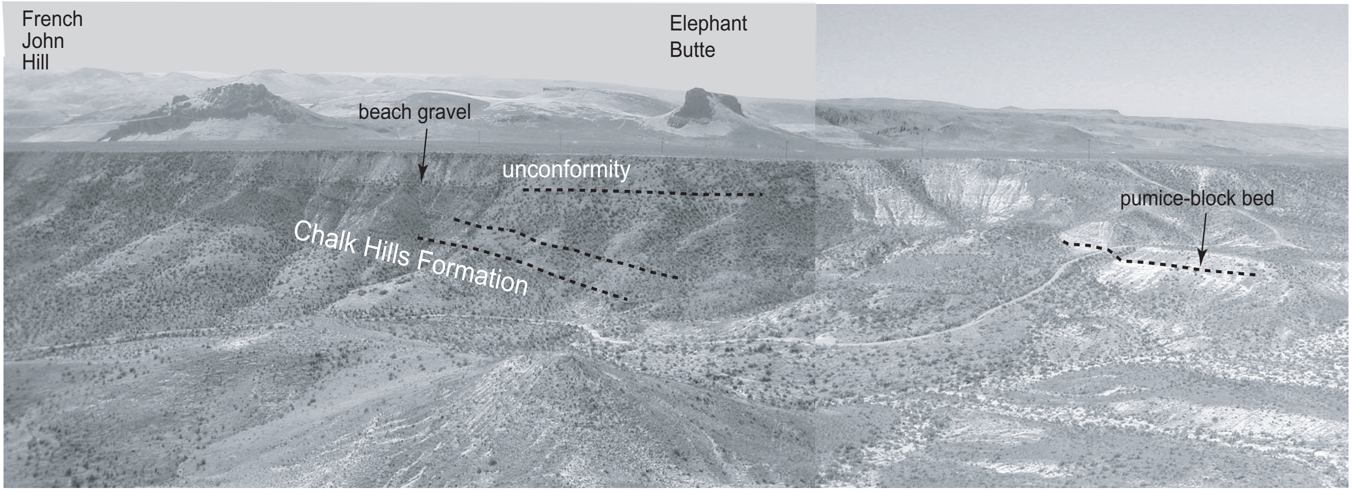

Figure 15. Angular unconformity between the tilted Chalk Hills Formation and the Glenns Ferry Formation. Base of the Glenns Ferry Formation is an 1-m-thick discontinuous sandstone, interpreted as a beach sand. Overlying the sandstone is 10 m of mudstone. Mudstone thickens to the north as shown in figure 19. View is looking south from mesa north of Stop 5.

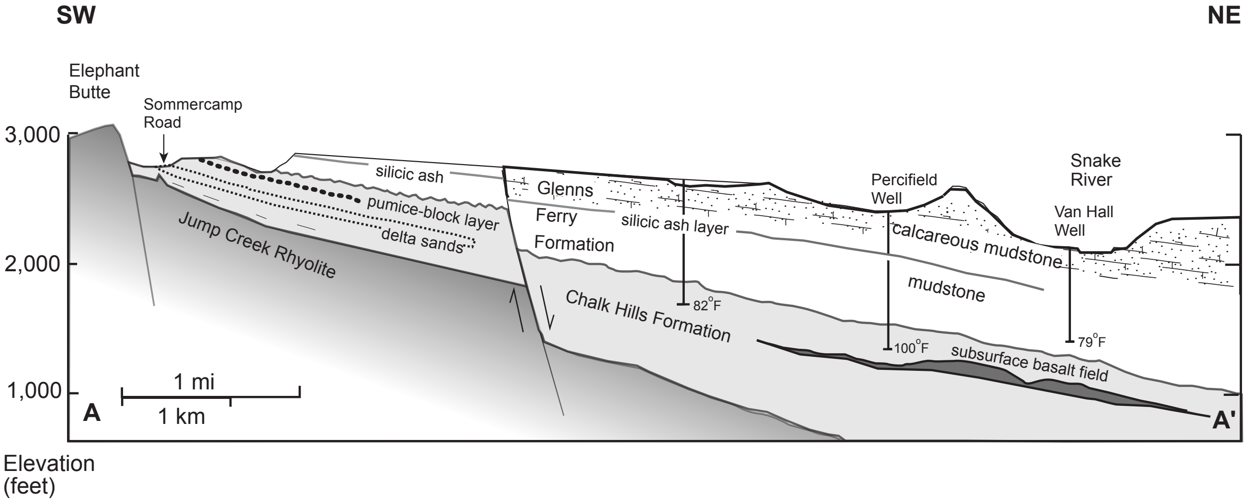

Figure 16. Stratigraphic cross section showing the position of calcareous mudstones of the upper Glenns Ferry Formation. Section is from Sommercamp Road area to the Marsing Hills. Location of section line A-A′ is shown on figure 5.

Mileposts on State Route 55 start at 0.0 at this junction

Mile-post	Inc.	
0.0	0.0	Junction U.S. Highway 95 and State Route 55, traveling east on State Route 55.
1.7	1.7	Marsing
2.7	1.0	Snake River bridge at Marsing. The river at Marsing flows in a natural low-gradient reach. The valley of the river is about 120 m (400 ft) below the surrounding plain. When the Bonneville flood roared through here 14,500 yr ago, the raging river was about 60-m (200-ft) deep over Marsing (O'Conner, 1993). Today, the average flows are about 240 m^3/s (8,500 cfs), but this reach accommodates spring flood flows greater than 1,420 m^3/s (50,000 cfs). A steady flow from springs of about 127 m^3/s (4,500 cfs) enters the river in the Thousand Springs-Hagerman reach, about 250 km (155 mi) away. This reach between the backwaters of Brownlee Dam in Hells Canyon and Swan Falls Dam, 56 km (35 mi) upstream has an average gradient of 0.00025 m/km (1.32 ft/mi), making this a long natural reach of the river without hydroelectric dams. The ecology and physical characteristics of the riverbank have been studied recently to provide information for legal proceedings between the U.S. Department of Fish and Wildlife and the State of Idaho over claims for Federal water rights to protect wildlife refuges on the islands (Ostercamp and others, 2001; Ostercamp, 1998; and Dixon and Johnson, 1999).
3.4	0.7	Lizard Butte east of the highway is the eroded remnant of a complex basalt volcano having many features of hydrovolcanism. The volcano erupted through the wet lacustrine sediment of the Glenns Ferry Formation. The deposits include deformed stream gravels, steeply dipping bomb-and-lapilli beds of scoria and surge deposits. The cap rock is a hard basalt agglutinate with chunks of white sediment, which is interpreted as a welded basalt spatter (Craig White, personal communication, 2003). Although the cap rock displays columnar jointing, it is welded spatter and not a lava flow as one would surmise from the highway view. Age is estimated to be late Pliocene or early Pleistocene.
3.9	0.5	Several light-colored hills forming the north rim of the Snake River valley are at about 10:00. These also are called the Chalk Hills, but they are not the Chalk Hills of the type locality of the Miocene Chalk Hills Formation. These "Chalk Hills" are sand and calcareous mudstone of the upper Glenns Ferry Formation and are of the floodplain and marsh facies (Reppening and others, 1994). They contain an important vertebrate fauna of early Pleistocene age (latest Blancan-earliest Irvingtonian), known as the Froman Ferry fauna. Important fossils, collected by local resident George R. Scott, are microtine rodents, early Pleistocene horse, puma, and an archaic

rabbit. Sediments are of reversed magnetic polarity (Van Domelen and Rieck, 1992), and estimated age is 1.5-1.7 Ma (Reppening and others, 1994).

4.8 0.9 **STOP FOR PICNIC LUNCH.** Ste. Chappelle Winery is the first post-prohibition winery in Idaho. Experimental vineyards were first planted in 1972, and the winery established in 1976 by the Symms Fruit Ranch. Well-drained loess soils, the microclimate of south-facing slopes of the Snake River valley, and the late growing season combine to produce Riesling, Chardonnay, Merlot, and other varietal grapes. There are now eight wineries in this area of which Ste. Chappell is the largest, shipping 200,000 cases per year. Figure 17 is a view from the winery.

6.8 2.0 Going north and then due east on State Route 55, we leave the Snake River valley and travel across the broad western plain.

9.2 3.6 Between Huston and the Lake Lowell turnoff is the “Lower Deer Flat channel”, a 3-km-wide, northwest-trending, gravel-mantled, middle-Pleistocene channel incised about 30 m into an upland surface of Glenns Ferry Formation capped by the Tenmile Gravel (Othberg, 1994). This probably is an old channel of the Snake River that was blocked to the southeast by the basalt fields of Kuna Butte and other large shield volcanoes. Eruptions of these lavas forced the river south to its present course on the south side of the plain.

16.2 7.0 Continue straight east through the stoplight at the intersection of State Route 55 and Caldwell Boulevard. This easterly continuation is named Karcher Boulevard, and there are no more mileposts. You will cross over the railroad tracks and the Interstate heading toward the Amalgamated Sugar Refinery.

18.0 1.8 Just past the sugar beet refinery, turn right (south) on Northside Boulevard and then left (east) to enter Interstate 84, heading east to Boise.

Mileages are now based upon mileposts of Interstate 84.

Mile-post	Inc.	
38.0	3.0	Just before Exit 38, the Interstate Highway descends over a basalt-mantled surface (one of the Amity or Deer Flat surfaces). This lava can be traced to Caldwell where it was ^{40}Ar/^{39}Ar dated by Othberg (1994) at 0.799±0.095 Ma and has a reversed magnetic polarity. From here east, the Interstate is on the Sunrise Terrace surface.
46.0	8.0	From Exit 46 (Eagle Road) the Interstate heads east, along a route for which we have a high-resolution seismic line all the way to Boise (about 8 mi east). Because of urbanization and traffic in this area, we used a route along the Union Pacific Railroad right-of-way, one mile south of the Interstate.
49.0	3.0	Take signs to CITY CENTER, as you negotiate the “Flying Y” complex of freeway overpasses.
49.5	3.5	About 0.5 mi beyond the Interstate “Flying Y” intersections, the highway descends to the Whitney Terrace surface.
51.8	2.3	Four lanes descend from the Whitney terrace onto the modern flood plain of the Boise River and downtown Boise. The Interstate Connector merges with city streets at Front Street. Continue east on Front Street.

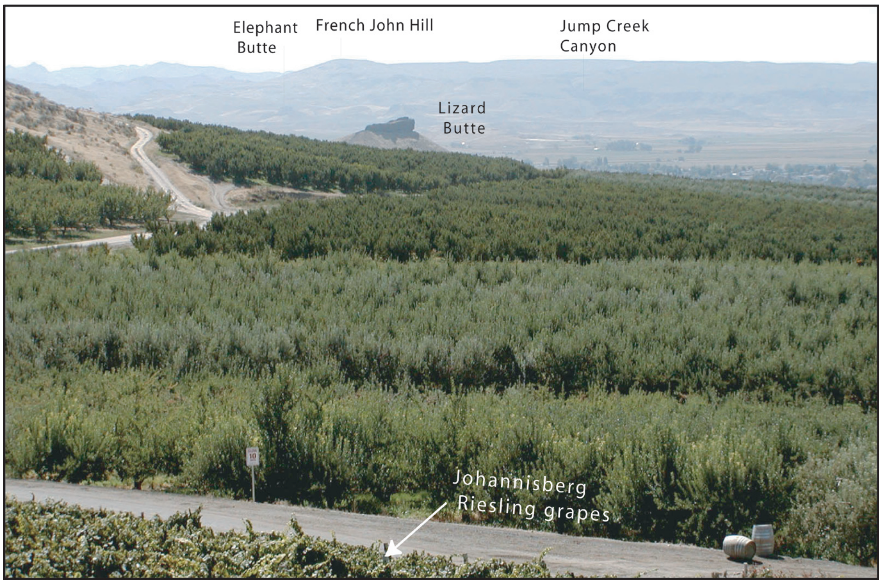

Figure 17. View to the south across the Snake River valley to the Owyhee Mountains from the Ste. Chappelle vineyards (Lunch Stop).

53.5 1.7 At the Capitol Boulevard stoplight, turn left (north-northeast), and the State Capitol Building should be in sight about 5 city blocks ahead.

53.8 0.3 At the Idaho State Capitol Building, turn left one half block in front of the capitol, and then right on 8th Street to the northwest corner of the State Capitol. The 1920 State Capitol building is constructed of Miocene Boise Sandstone from the Table Rock Quarries (Stop 9).

Reset mileages at the 8th Street and State Street intersection.

WESTERN BOISE FOOTHILLS LEG OF FIELD TRIP

Mileage
Cum. Inc.

0.0 0.0 This leg of the field trip starts at 8th and State Street, the northwest corner of the State Capitol grounds (fig. 18). Continue 3 blocks northeast on 8th Street and turn left (northwest) on Hays Street.

0.0 0.2 Hays Street and 8th Street. Travel 0.6 mi northwest on Hays Street.

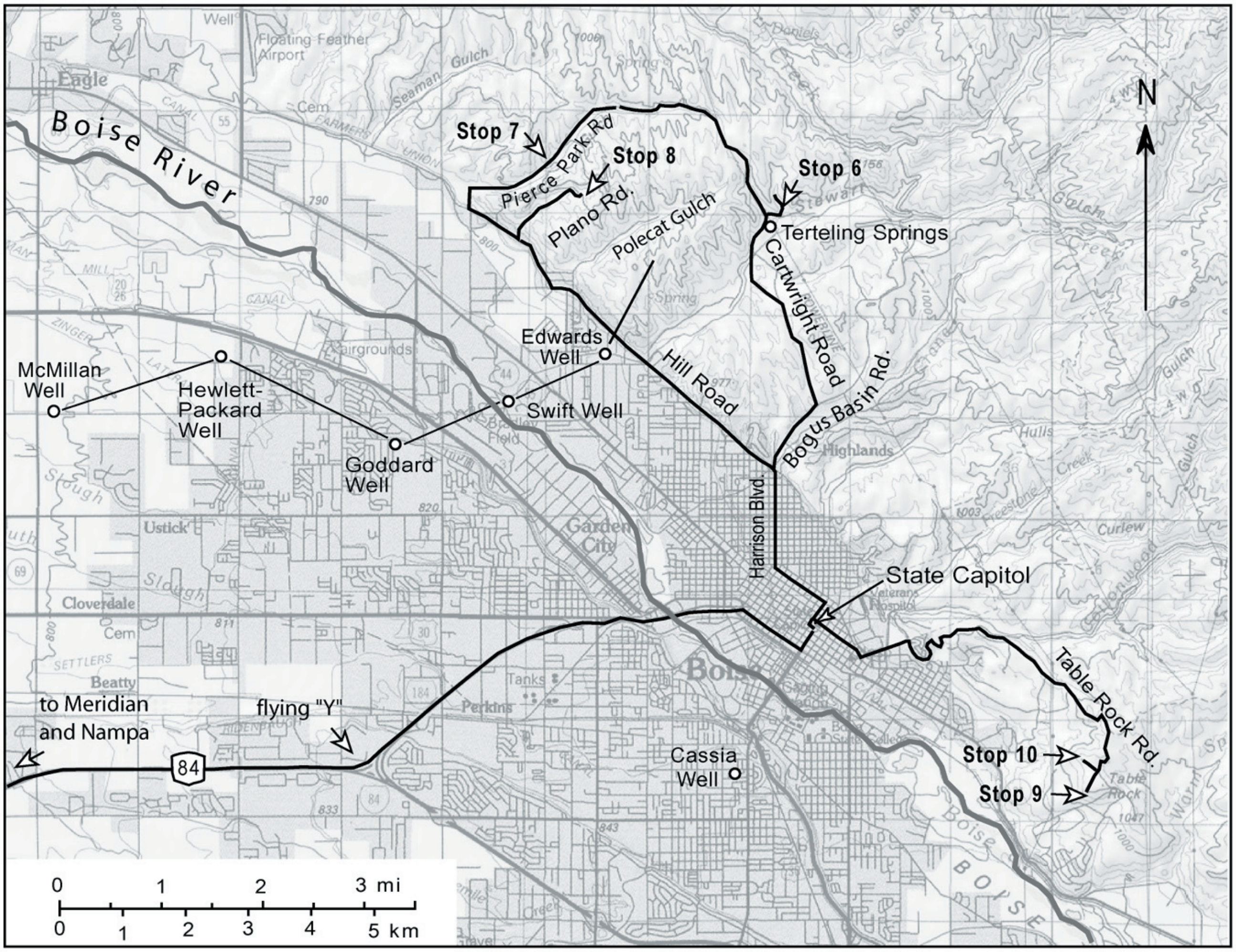

Figure 18. Map showing route of trip through the Boise foothills.

0.8	0.6	Bear right (north) and merge with Harrison Boulevard. Continue straight ahead (north) to the Hill Road intersection.
1.8	1.0	Hill Road stoplight. Continue straight ahead. Harrison Boulevard turns into Bogus Basin Road.
2.1	1.0	In the road cuts behind the buildings, on the left (west), is fine- and medium-grained sand with hummocky cross stratification (HCS) (Gallegos and others, 1987). HCS is produced by currents near the wave base, induced by storm waves. This type of cross stratification indicates near shore sedimentation, and under oceanic conditions within a 10–20-m depth (Walker and Plint, 1992).
2.6	0.5	Turn left (northwest) onto Cartwright Road. This turn is beneath the green-lawn-covered hill of the J.R. Simplot Mansion. Sediment along the road is mostly nearshore muds and sand of the Terteling Springs Formation.
3.3	0.7	Crest of hill. Ahead are hills with the conspicuous contact between mudstone of the Terteling Springs Formation and the overlying coarse Gilbert-style delta sands of the Pierce Gulch Sand (fig. 19). The mudstone is grass covered because of good moisture retention of the fine soil, whereas the Pierce Gulch Sand has only dark bitterbrush clumps with roots that reach deeper into the ground for moisture on dry sandy slopes. This vegetation contrast is seen on most south-facing slopes of these lithologies. North-facing slopes in the foothills have a substantial mantle of loess soil, 1–4-m thick, which supports bitterbrush and sage thickets.
4.6	1.3	Sediments dipping 28° W. in the road cut are inferred to be the Chalk Hills Formation. Sediments of the overlying Terteling Springs Formation, at the gate to the Owyhee Motorcycle Club, 0.2 mi to the northeast, are dipping only 12°. Generally, it is inferred that an unexposed angular unconformity exists between these units. This is the only place where existence of an angular unconformity can be demonstrated within the lacustrine sequence in the foothills. Possibly, it compares with the unconformity at Stop 5 along the Owyhee Mountains front.
4.8	0.2	Park for Stop 6.

Stop 6. Oolites and Fossil Clams of Lake Idaho, Owyhee Motorcyle Club in Stewart Gulch

Park at the entrance to the Owyhee Motorcycle Club. View the foreset beds at the gate, go through the gate, and walk around the hill to the northeast, observe the sediments in the excavated cut at the bleachers on the racetrack, and then proceed about 200 m up the gulch to the oolites. Coarse sand foreset beds of a Gilbert-style delta are overlain by Terteling Springs Formation mudstone at the entrance gate of the motorcycle club (figs. 20 and 21). This contact is interpreted as a “flooding surface” caused by a rise in lake level. Alternatively, one might argue it is the result of lobe switching of delta distributaries, but mass-failure deposits into deep water seen around the hill to the east suggest deepening of waters. The foreset-bedded sand unit at the entrance gate crops out again as cemented sandstone in the canyon of Dry Creek, about 1 mi north of here. In Dry Creek valley, this sand is one layer of foreset-bedded sandstone about 25-m (80-ft) thick. It is believed that Terteling Springs, just below the road here, is

Figure 19. Contact of the Pierce Gulch Sand overlying mudstone and oolite bars of the Terteling Springs Formation. View is to the northwest from the Cartwright Road across Stewart Gulch. Greenhouses in the foreground are heated by geothermal water.

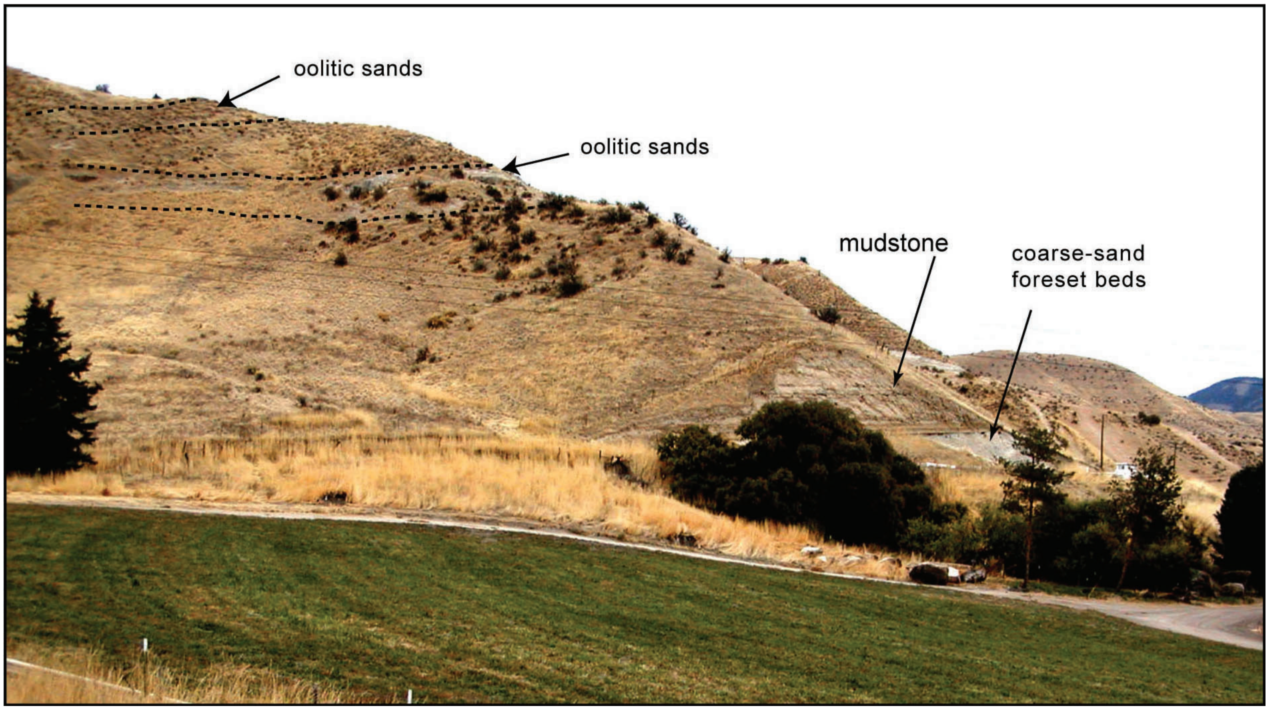

Figure 20. Coarse sand of a Gilbert delta overlain by mudstone and the oolite bars at Terteling Springs in Stewart Gulch. View is to the northeast from Cartwright Road.

discharge from this permeable sand unit intercalated within mudstones of the Terteling Springs Formation.

Walk through the gates and continue left around the hill about 200 m past the bleachers to the beer and pop stand. In the excavated cut behind the stand is a bed of coarse orange sand, over 3-m thick, and fine beds contorted by soft sediment deformation. The sand contains abundant white shells of gastropods and clams chaotically oriented in the sand (fig. 22A). I interpret the sand as a mass-failure into deep water, derived from failure of a shoal or beach associated with a delta. The sand was deposited rapidly on the lake bottom causing soft sediment deformation of the fine beds.

Continue walking up the gulch about 100 m beyond the racetrack and through an unmaintained fence to a smooth rock ledge at the foot of the hills. This rock ledge is made up of carbonate-coated sand grains, commonly called "oolites" (fig. 22B). Formation of lacustrine oolites occurs in wave-agitated waters of beaches and shoals. Origin of ooids is still debated, but precipitation of concentric microlayers from carbonate-saturated waters onto grains of fine sand seems clear here. Davaud and Giradclos (2001) show that biofilms act as a catalyst or substrate for submicron-sized calcite crystals forming on oolites in temperate, freshwater Lake Geneva (Switzerland), at depths of 1–5 m.

Several lenses of oolitic sand occur here over a stratigraphic interval of 120 m (fig. 23). On the south side of the western plain, these oolite occurrences have been interpreted as a transgressive unit at the base of the Glenns Ferry Formation (Malde and Powers, 1962; Swirydczuk and others, 1979, 1980a, 1980b, Reppening and others, 1994). Wood and Clemens (2002) agree they are a transgressive unit, and propose that the oolites are an indication that Lake Idaho was a closed-lake basin of increasing alkalinity. The closed-basin environment is confirmed by a ^{13}C isotopic analysis of del^{13}C

Figure 21. Closeup of foreset-bedded coarse sand overlain by mudstone of the Terteling Springs Formation.

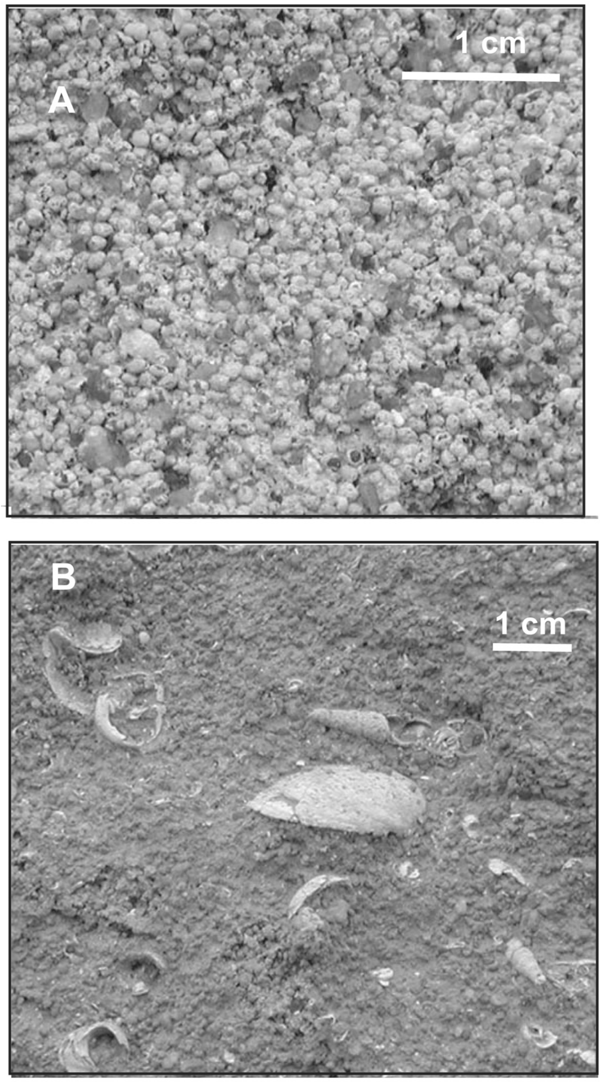

Figure 22. (A) Carbonate-coated grains (oolites), mostly about 0.8 mm in size from the outcrop at the Owyhee Motorcycle Club. (B) Fossil clams and snails in a coarse sand at the Owyhee Motorcycle Club. Shells are scattered without orientation indicating this may be a mass-wasting deposit collapsed from a delta front and not a beach deposit.

= +2.0 for carbonate in oolites collected from drill cuttings from a depth of 40 m in the Cassia Street water well in central Boise (fig. 18), about 8 km (5 mi) south of here (Cavanagh, 2000). Worldwide, the del^{13}C of closed-lake carbonates range from -2 to +5, whereas open-lake carbonate ranges from -5 to -15 (Talbot, 1990).

Mileage

Cum.	Inc.	
		Walk back to the vans parked at the entrance to the motorcycle club. Continue driving northwest on Cartwright Road.
5.8	1.0	Crest of the hill. The road traverses the contact of the Pierce Gulch Sand over the Terteling Springs Formation.
6.3	0.5	Pierce Park Road. Bear left (southwest) on Pierce Park Road.
6.7	0.5	Many springs occur at the contact of the base of the permeable Pierce Gulch Sand upon mudstone along this road, as indicated by the abundant black locust, cottonwood, and willow trees and blackberry thickets.
7.6	0.9	Mudstone of the Terteling Springs Formation with a 2-cm-thick white silicic volcanic ash. Near here, visible when the grader cleans the road cut, is a white sand hummock within the mudstone, probably storm-wave reworked sands that avalanched from a delta edge.
7.9	0.3	Pull off on the right side of road and park at the entrance to the sand quarry in the Pierce Gulch Sand. Walk down the road (south) to the road cut in Terteling Springs Formation.

Stop 7. Pierce Park Road: Pierce Gulch Sand Over Mudstone of the Terteling Spring Formation

The quarry exposes 20-m-thick foreset beds of the Pierce Gulch Sand. The sand is a Gilbert–style delta of coarse sand. Walk down the road (about 150 m) just past the high road cut in Terteling Springs Formation mudstone, on the west side of road, to see the 20-cm-thick, white silicic volcanic ash near the top of the mudstone unit. The coarsest grains at the base

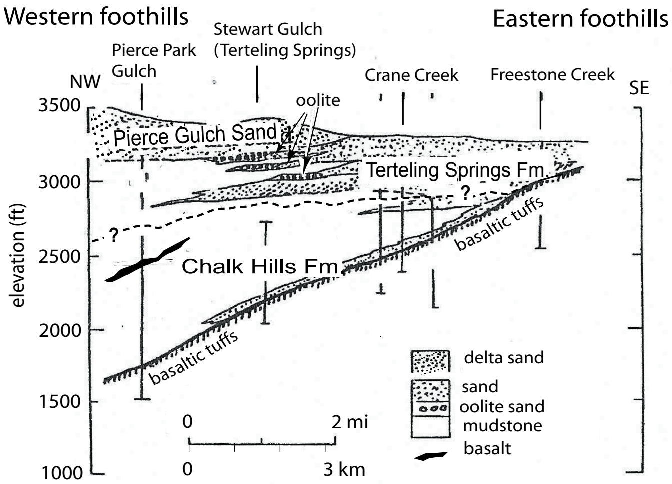

Figure 23. Stratigraphic diagram showing relation of the Chalk Hills Formation with the overlying Terteling Springs Formation and the Pierce Gulch Sand (from Wood and Clemens, 2002).

of this ash layer consist of 0.15- to 0.2-mm shards of white pumice and very light-gray glass. This size suggests it came from a volcanic source within several hundred kilometers. This relatively thick ash occurs in many places in the western foothills and is a good marker near the top of the Terteling Springs mudstone.

Mileage		
Cum.	Inc.	
		After this stop, return to vans and continue down Pierce Park Road.
9.1	1.2	Pierce Park Road and Hill Road. Turn left (east) onto Hill Road.
9.7	0.6	North Plano Road and Hill Road. Turn left (north) on North Plano Road, and continue northeast. We will travel 1.4 mi up this road.
	0.1	End of pavement. Continue on North Plano Road. It is uncertain whether this is still a private road, despite the abundance of “no-trespassing notices” on the side of the road. The road serves several residences at the top of the hill. I think it now is a public county road.
	0.8	Turn around and park at the switchback, which is a posted entrance to private sand quarries. Walk back about 150 m to the road cut on the south side of the road.

Stop 8. North Plano Road: Base of the Pierce Gulch Sand

The road cut on this dirt road into the foothills is the only good exposure of the base of the Pierce Gulch Sand over mudstone of the Terteling Springs Formation. The contact is so easily mapped on air photos by contrast in vegetation and soil that one might believe it is an unconformity. However, at this locality the deposition appears continuous, and the boundary between these two different lithologic units is simply that of a coarse-sand delta prograding and downlapping over prodelta mudstone. On a large scale, when viewed from a distance, the lower sand crossbeds shallow downward in slope and appear tangential to the contact.

Geophysical logs of water wells west of here show a major delta unit in the upper section (fig. 24). At the McMillan Well, 10 km (6 mi) west of here, the delta sand thickens to 210 m (700 ft). The delta unit is built out into a deeper lake basin and is thicker there because of “greater accommodation depth”.

In this road cut, a 1.5-m-thick bed of coarse sand overlies mudstone, and the sand is overlain by yet another mudstone. The main thick body of coarse sand lies just a few meters above the road cut (fig. 25). Mudstone fingers and lenses penetrate the sand, suggesting the muds were semisoft when overlain by the sand. Small sand dikes also wedge upward about 0.3 m into the overlying mudstone. The boundaries are quite sharp and appear conformable, suggesting that sand prograded rapidly over the mud bottom of the lake.

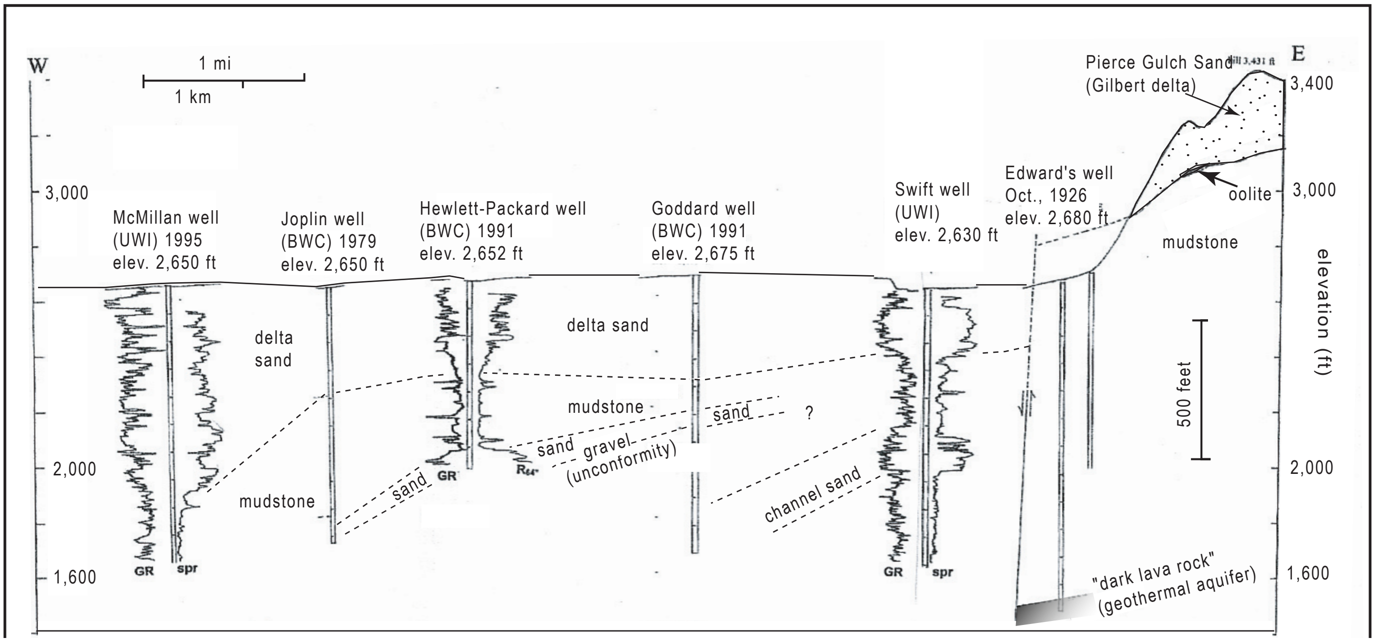

Figure 24. Stratigraphic section and well logs from Polecat Gulch in the foothills to west Boise, showing the Pierce Gulch Sand and equivalent delta facies in the subsurface. Well locations shown in figure 18. GR, natural gamma log; spr, single-point resistance log; and R_{64}, 64-inch normal-resistivity log. Well logs courtesy of United Water Idaho, Inc. (UWI), and its predecessor, Boise Water Company (BWC).

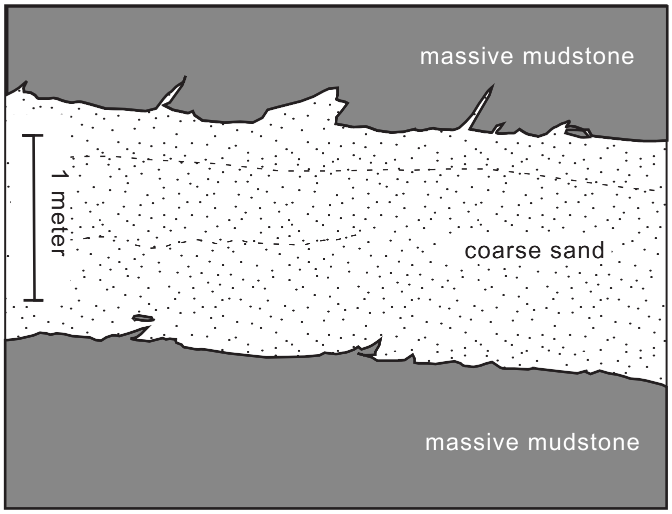

Figure 25. Tracing of photo showing an bed of coarse sand interbedded within mudstone, just beneath the base of the massive Gilbert-style delta of the Pierce Gulch Sand at North Plano Road. The sand bed is interpreted to be a sublacustrine avalanche out on to the muddy lake bottom, formed as the main foreset sand body was advancing basinward.

Mileage Cum.	Inc.	
		After viewing this stop, drive 1.4 mi back to Hill Road.
9.7	1.4	Return to the intersection of Hill Road and North Plano Road and turn left (east) on Hill Road.
11.1	1.4	Hill road makes a 90° turn to the left (east).
11.9	0.8	To the right (south) is the road to Edward's Greenhouse, a highly successful geothermally-heated greenhouse operation raising garden plants and decorative flower baskets of all sorts for the Boise market. Location of the Edward's well is shown in figure 18. The geothermal system here is of historical importance in Idaho groundwater law, because in 1931, the Idaho Supreme Court issued a landmark decree (Silkey v. Tiegs) on the doctrine of "the illegality of mining of an aquifer". The court interpreted the declining pressure and artesian-well flows of hot water to be the result of discharge exceeding recharge of an aquifer. In those situations, the rights of the junior appropriators (those owners of the later wells) to produce water are curtailed. The wells are about 350-m (1,150-ft) deep, into a "dark volcanic rock", probably a rhyolite, and produce 47° C (117° F) water (Young and others, 1988).
12.4	0.53	6th Street and Hill Road stoplight, continue southeast on Hill Road.
13.8	1.4	Bogus Basin Road and Hill Road and Bogus Basin Road (Harrison Boulevard) intersection. Turn right (south) on Harrison Boulevard, and travel 1.0 mi to where Harrison merges with the east-bound lane of Hays Street, follow east on Hays Street for 0.8 mi to 9th Street.
15.6	1.8	9th Street and Hays Street. Turn right (south) on 9th Street.
15.8	0.2	State Street and 9th Street. Turn left (east) on State Street.
15.9	0.1	Idaho State Capitol Building, 8th and State Street.

Reset mileages at the 8th Street and State Street intersection.

EASTERN BOISE FOOTHILLS LEG OF FIELD TRIP

Mileage Cum.	Inc.	
0.0	0.0	This leg of the trip starts at the intersection of 8th Street and State Street, the northwest corner of the State Capitol Building grounds. Travel east on State Street.
0.1	0.1	Intersection of Fort Street and State Street. Bear right (east) onto Fort Street.
0.4	0.3	Turn left (north) on Reserve Street.
0.6	0.2	Intersection of Mountain Cove Road and Reserve Street, continue north on Reserve Street. The dike on the northwest (left) side of the street was built in 1998 to increase the volume of the sediment retention reservoir where Cottonwood Creek flows from the foothills. The September 1996 foothills fire focused awareness on potential debris flows out of the foothills gulches, particularly after major fires in the watersheds.
0.9	0.3	Main road bears right and uphill (east) and changes name to Shaw Mountain Road at this intersection with San Felipe Way. Three hundred feet northwest along a gated gravel

road is the Boise Geothermal, Inc. Well No. 1, drilled to a depth of 634 m (2,080 ft). Idaho batholith granite is at a depth of 512 m (1,680 ft) in this well (Burnham and Wood, 1983).

1.0 0.1 The basalt of Aldape Heights crops out along Shaw Mountain Road to about this intersection with Santa Paula Place. This basalt is intercalated with sands of the Chalk Hills Formation. Clemens and Wood (1993) obtained a whole-rock K-Ar age of 9.5±0.6 Ma. They

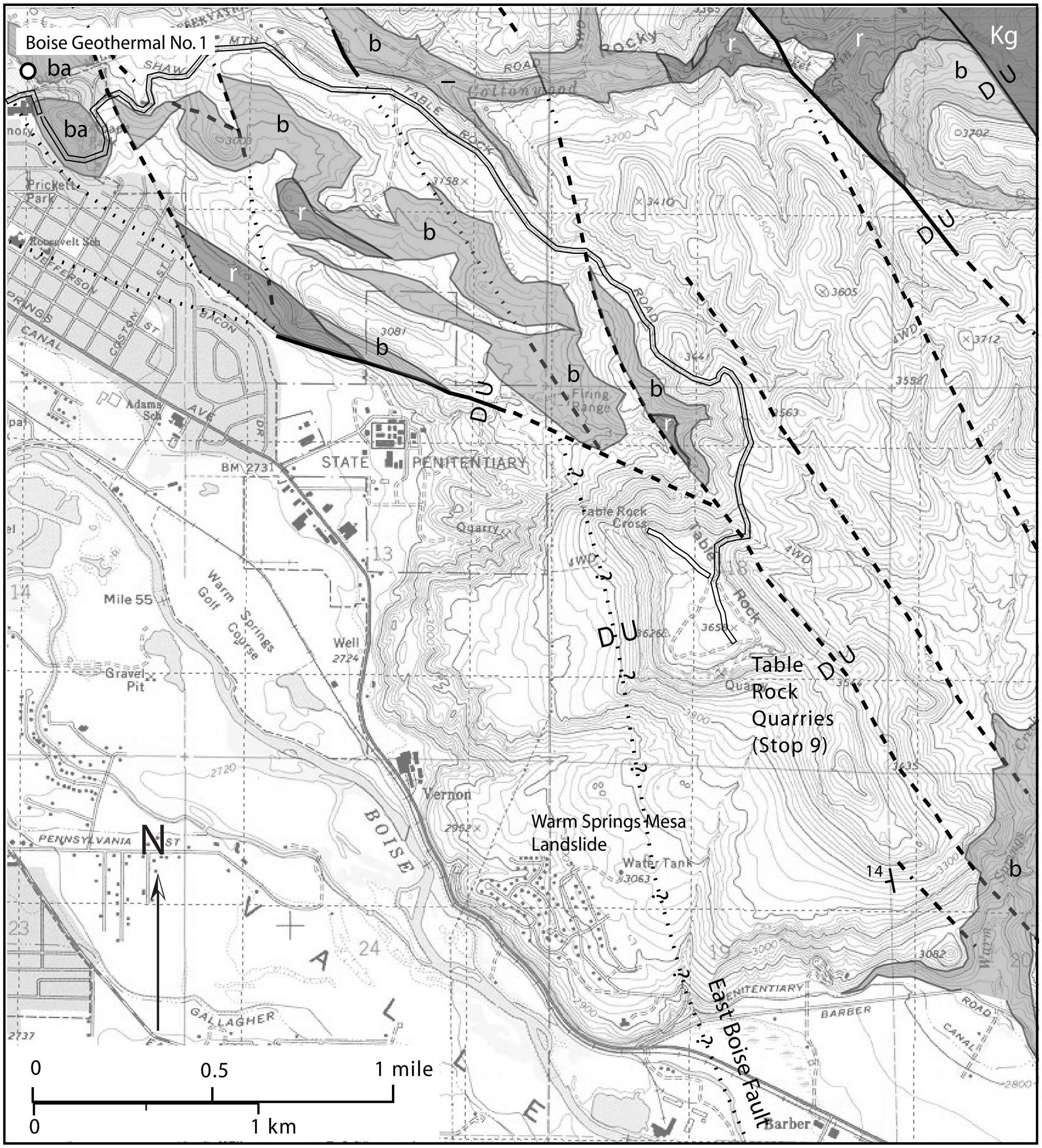

Figure 26. Geologic map showing the route to Table Rock. The Table Rock area is a downfaulted block, with respect to the foothills on the north. Because it is structurally lower, it contains one of the more complete stratigraphic sections in the foothills of 210 m (700 ft) of fluvial and lacustrine sediment over the Miocene rhyolite and basalt. Symbols on map: Kg, granodiorite of the Idaho batholith; r, Quarry View Park and Cottonwood Creek rhyolite (11.8±0.6 and 11.3±0.3 Ma, respectively); b, basalt and basaltic tuffs; ba, basalt of Aldape Park; and unshaded areas are fluvial and lacustrine sediment (after Clemens and Wood, 1993).

show that this rock petrochemically matches basalt that occurs in the Capitol Mall Geothermal wells by the Statehouse, at a depth of about 223 m (730 ft), indicating vertical separation due to dip of beds and offset along faults is about 260 m (850 ft) between the outcrop and the wells by the Statehouse.

2.0	1.0	Turn right (east) on Table Rock Road at this intersection of Shaw Mountain Road and Table Rock Road.
4.0	2.0	Bear right (south) on Table Rock Road at this intersection with E. Wildhorse Lane (private lane).
4.2	0.2	Gate unlocked between 1 hour before sunrise and 1 hour after sunset. This point is in a saddle between hills and is the location of the normal fault (fig. 26) that down drops the Table Rock section of sediments to the southeast relative to the foothills to the north.
4.5	0.3	Park for Stop 9.

Stop 9. Table Rock Quarries

Park here and procede 0.25 mi to the southeast along a deeply-rutted road to the rim of the mesa and the quarries for the “Boise Sandstone”.

Table Rock is a mesa capped by silica-cemented sandstone, forming a prominent landmark above east Boise. The mesa is comprised of younger lake and stream sediments faulted down relative to the northern foothills, about 300 m (1,000 ft), thus preserving a 200-m (700-ft) section of sedimentary strata (Wood and Burnham, 1987; Clemens and Wood, 1993) (fig. 26). The 15-m-thick sandstone layer at the top (fig. 27) has been quarried for over 100 yr and widely marketed as a dimension stone. It is the stone of which the Idaho State Capitol Building was constructed in 1920. This “Boise Sandstone” also is a standard for many rock mechanics and petroleum reservoir experiments (Wong and others, 1997). Porosity of 0.27 and a permeability of 910 mD (9.6×10^{-4} cm/s, hydraulic conductivity) are reported by Kovscek and others (1995).

The massive character of this sandstone makes it a good stone for sculptors and for dimension stone. I have puzzled over how a 15-m-thick layer of sand, of such uniform grain size ($D_{10} = 0.2$, $D_{50} = 0.35$, $D_{95} = 0.7$ mm), was deposited. Gallegos and others (1987) suggested it was a gravity-driven mass flow beneath the lake based on the character of its basal scour surface. Above the massive sandstone is 5 m of bedded sandstone with 0.5 mm coated grains (ooids) and rip-up slabs of coarse sandstone mixed with ooids (fig. 27 and 28). Above the bedded sand is thin-bedded mudstone and uncemented sand and sandy gravel.

Silica cementation of the sand occurred as silica-saturated geothermal waters percolated through permeable beds and cooled allowing the dissolved silica to precipitate. Silica-cemented sandstone around the western plain commonly occurs within several kilometers of fault systems. The faults were conduits for upward flow of silica-bearing hot water from depths of a few kilometers.

From the quarries is the best view of the Pleistocene terrace sequence of the Boise River Valley (fig. 29). Othberg (1994) established a chronology for the four terraces observed

Figure 27. Massive medium-grained sandstone at the Table Rock Quarries. This 15-m-thick layer is the “Boise Sandstone” sold throughout the United States as a dimension stone during the early 20th Century. The layer can be traced laterally for at least 800 m. Sedimentary architecture of this sand has not been studied, and its origin remains uncertain. It is overlain by bedded sands that contain up to 30 percent coated grains, that look very much like carbonate coated oolites, but do not effervesce. The sands also contain rip-up clasts of oolite-bearing coarse sand (fig. 28). The upper bedded sands display low-angle, tangential cross stratification. Above the sandstone is mudstone and pebbly sands.

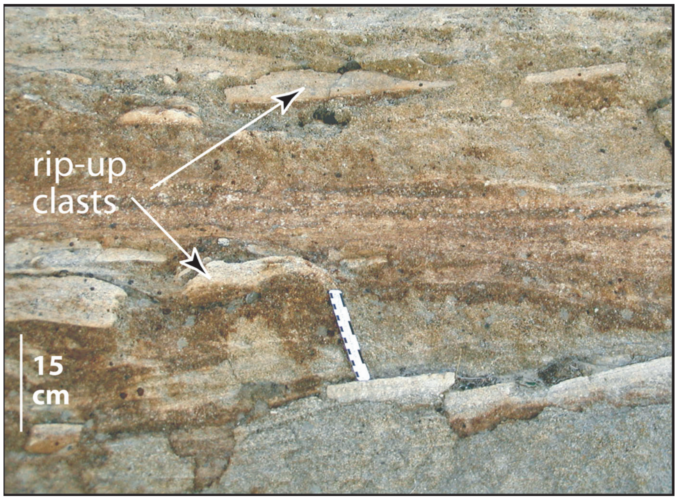

Figure 28. Rip-up clasts (light colored) of cemented coarse sand with 0.5 mm coated grains within bedded coarse and small-pebble sandstone. Locality shown in figure 27 at the Table Rock Quarries.

here by dating the basalt layers that lay upon the terrace surfaces. He also recognized the much older (but undated) Bonneville gravels on the southeastern skyline of figure 29. The terraces are typically overlain by 15 to 30 m of gravel on a strath surface of eroded lacustrine sand or mudstone (Squires, 1992). Downward erosion of the Boise Valley leaving this sequence of abandoned flood plains was in response to lowering of base level and related downcutting by the Snake River. During the late Pliocene and the Quaternary, the Snake River was downcutting the entrance to upper Hells Canyon as shown by the "base-level decline" of figure 3. This is a good place to address the question of why rivers incise episodically leaving broad terrace remnants. Othberg (1994) indicated that climate fluctuation in the Quaternary likely was the cause that triggered incision. However, questions remain about whether it was related to a change in sediment load or discharge characteristics associated with glaciation in the headwaters of the Boise River or related to overall climate change. Pazzaglia and Brandon (2001) present a model for coastal streams where they associate fill and flood plain deposition with the increased load accompanying deglaciation. In this model, strath incision occurs during periods of alpine glacial advance. Their study of coastal streams, however, also is complicated by sea-level fluctuation. At this time, the factors tht controlled or triggered downcutting and terrace formation in this region are unknown.

Mileage

Cum.	Inc.	
		After viewing the quarries return to the parked vans and proceed west toward the group of radio towers and continue on to the parking area at the large white cross.
4.7	0.2	Park for Stop 10.

Stop 10. Table Rock Cross Viewpoint: View to the West Over Boise and the Western Plain

This final stop of the trip looks west over the city of Boise (fig. 30). Directly below us are the grounds of the 1860 Idaho Territorial Penitentiary and the Boise Warm Springs geothermal area. The prison buildings were constructed by prisoners from sandstone quarried from the hill below. The area now is a public park and houses the Idaho Museum of Mining and Geology. From this area, one can embark on short hikes on well-marked trails into the foothills. City bus service along Warm Springs Avenue leaves every 30 minutes from downtown at 8th and Idaho Street and takes you to within

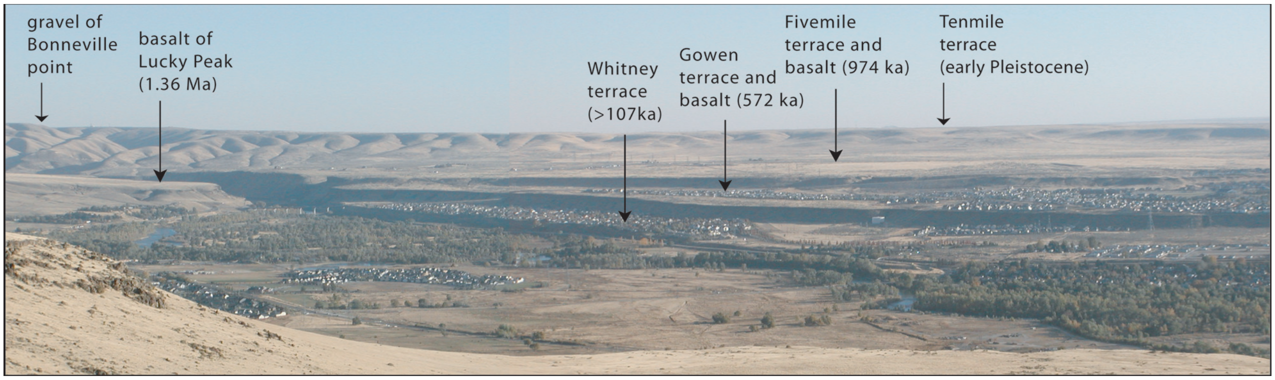

Figure 29. View to the southeast from the Table Rock Quarries. Othberg (1994) obtained Pleistocene ages on the several basalt units that flowed over the successively lower braided floodplains of the Boise River. The early Pleistocene Tenmile terrace surface forms the skyline. This surface is 150 m (500 ft) above the modern Boise River.

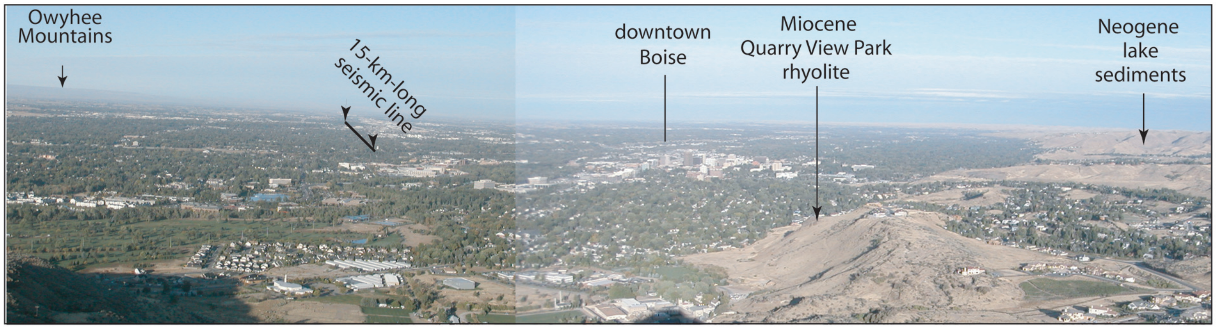

Figure 30. View to the west over the Boise Valley and the western Snake River Plain. Building area at the bottom of the hill, beneath this viewpoint, are the grounds of the 1860 Idaho Territorial Penitentiary and the Boise Warm Springs area.

300 m (0.2 mi) of the park on weekdays; however, there is currently no weekend service.

The outcrop of the Quarry View Park rhyolite is described by Wood and Burnham (1987) and shown by the arrow in fig. 30. Clemens and Wood (1993) report a K-Ar age of the rhyolite of 11.8±0.6 Ma on andesine plagioclase separates. The rhyolite is overlain by basalt, which is in turn overlain by a ledge of cemented conglomeritic sandstone. The overlying lacustrine and fluvial sediments dip generally west-southwest 4–10º. Several northwest-trending normal faults trace through the foothills and beneath downtown Boise (Liberty, 1998). Despite our high elevation at the Table Rock viewpoint, 1,108 m (3,636 ft), we are on a down-thrown block relative to the hill below containing the Miocene rhyolite (figs. 26 and 30). Throw on the fault between the rhyolite and the flat area below is about 210 m (700 ft)(Wood and Burnham, 1987).

All of the state office buildings, many commercial buildings in downtown Boise, and many of the older homes in northeast Boise are heated by hot water from wells. The original two hot water wells were drilled 123-m (404-ft) deep in the warm springs area by the Penitentiary in the early 1900s. They initially had an artesian flow of 351 l/s (550 gallons/minute) of 77° C (170° F) water, but pressure has declined, and the wells must be pumped. The Warm Springs Water District is the oldest geothermal heating district in the United States. The State of Idaho, the U.S. Veterans Hospital, and the city of Boise since the 1980s, produce water from wells 600–920-m (2,000–3,000-ft) deep beneath downtown Boise and along the edge of the foothills. A reinjection well was drilled in 1994 near the State Historical Museum, 5 blocks south of the Convention Center to a depth of 975 m (3,200 ft). Location was based on a seismic reflection survey by Liberty (1998) that imaged the faulted basalt above the rhyolite. Flow from the rhyolite aquifers below 670 m (2,200 ft) was about 57 l/s (900 gallons per minute) of 77° C (170° F) water, and these aquifers have a shutin artesian hot-water-column head of 13 m (43 ft) above ground level. It is the most successful production well, but due to its location at the tail end of the building-heat-circulation system, it is used as a reinjection well. The geothermal aquifer system is in the same fractured rhyolite rock exposed on the upthrown fault block in the foothills below. Production is just now increasing for the city of Boise system to serve new buildings, but it is uncertain whether aquifer pressure and temperature will sustain continued exploitation in this downtown area. The area south of the Boise River has never been explored by deep wells. It is likely the downfaulted aquifer is deeper and hotter immediately to the south.

This is the end of the trip, and vans will return back to the Convention center.

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