Field Guide to the Quaternary Geology
of the Boise Valley and Adjacent
Snake River Valley, Idaho

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Staff Report 96-1
March, 1996
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FIGURES

1. Map showing the location of the Boise Valley and the field trip stops .................. 3
2. Distribution of Boise Valley terraces ......................................................... 4
3. Diagrammatic profiles of the eastern and western Boise Valley terraces .......... 5
4. Stereopair of a block diagram showing the sequence of terraces ................. 5
5. Correlation of Boise Valley terraces ......................................................... 7
6. Locations of selected volcanic vents and flow directions of basalt flows ....... 10
7. Results of dating of basalts in the Boise Valley and adjoining area .......... 11
8. Profile and cross section of the Boise River canyon near Lucky Peak Dam .... 11
9. CaCO$_3$ equivalent index for duripans in the Boise Valley ....................... 15
10. Opaline SiO$_2$ index for duripans in the Boise Valley ......................... 15
11. Map of the Bonneville Flood route .................................................... 17
12. Profiles of the Snake River, Portneuf River, and Marsh Creek .................. 18
13. Generalized late Pleistocene history of lake levels in the Lake Bonneville basin ... 19
14. Map of Bonneville Flood features ...................................................... 21
15. Geologic evidence for maximum flood stages ...................................... 22
16. Major flood deposits and the inundated area near Farewell Bend .............. 24
17. Maximum stages and calculated profiles for the Farewell Bend reach .......... 25
18. Flood features, topography, and boulder measurement locations at Walters bar ...... 38
19. Geologic map of the Walters Ferry Quadrangle ..................................... 40,41
TABLE

1. Classification of the Power, Purdam, Elijah, and Chilcott soil series .......... 12
Field Guide to the Quaternary Geology of the Boise Valley and Adjacent Snake River Valley, Idaho

Kurt L. Othberg¹, Jim E. O'Conner², and Paul A. McDaniel³

INTRODUCTION

This field guide was developed for the 1995 annual field trip of the Friends of the Pleistocene, Pacific Northwest Cell, which was held April 28-30 of that year.

To present the Quaternary geology of the area, the guide first reviews the Tertiary geologic history of the Western Snake River Plain, then describes the Pleistocene gravel terraces and basalt eruptions, the soils formed on the Quaternary surfaces, and finally, the Bonneville Flood. The guide is based on research conducted in late 1980s and early 1990s, and it includes the resulting soils data, terrace correlations, radiometric dating of basalts, and hydrologic calculations for the Bonneville Flood.

The field guide reflects the research that was organized according to two themes: the Boise Valley terraces and the Bonneville Flood. The suggested field trip included in the guide is similarly organized with the first day viewing terraces and terrace soils, and the second day observing Bonneville Flood features.

LOCATION AND GEOLOGIC SETTING

The area called the Boise Valley refers to the lower valley and terraces of the Boise River across the western Snake River Plain (Figure 1). The Boise River heads in the Sawtooth and Smokey Mountains of central Idaho. The river drains an extensive area of mountainous terrain before it exits the mountains near Lucky Peak Dam southeast of

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Boise (near Stop 1.1 in Figure 1).

The Boise Valley and other major river valleys are incised about 150 meters (500 feet). The sides of these valleys are benched with terraces (Figures 2 and 3). The most complete terrace sequence is south of the city of Boise (Figure 4).

The western Snake River Plain is both a northwest-trending physiographic lowland (Figure 1) and a great structural graben separating the Cretaceous Idaho batholith of west-central Idaho from batholith outliers in southwestern Idaho. The volcanic rocks of the eastern Snake River Plain probably formed by plate movement to the southwest over a hot spot presently active in the Yellowstone National Park area. The western plain, however, is a structural basin with features similar to continental rifts (Mabey, 1982; Smith and others, 1985; Wood, 1994). Although the basin is a well-defined graben, structural downwarping is present along its margins. Numerous marginal faults trend northwest-southeast with movement down toward the center of the basin (Malde, 1959, 1991; Wood and Anderson, 1981; Wood, 1989; Wood, 1994). Vertical displacement along the northern faults may be as much as 2,744 meters (9,000 feet). The rift began to open after eruption of the Columbia River flood basalts and passage of the early stages of the Snake River Plain hot spot. The Tertiary development of the western plain was controlled by this rifting. Prolonged subsidence entrapped the drainage and filled the basin with Miocene and Pliocene sedimentary and volcanic rocks. Basalt eruptions were both subaerial and subaqueous (Jenks and Bonnichsen, 1989). Sediments accumulated in the new basin in lakes, streams, and on alluvial fans (Middleton and others, 1985; Smith and others, 1985). These deposits form the Idaho Group which is mostly Lake Idaho sediment.

Biogeographical evidence suggests the Tertiary drainage outlet for the western Snake River Plain was westward and southwestward through Oregon and northern California (Malde, 1991). Wheeler and Cook (1954) presented physiographic evidence for capture of the ancestral Snake River by headward erosion of the Hells Canyon tributary of the Salmon River. The youngest sediments of Lake Idaho, within the upper part of the Pliocene Glenns Ferry Formation, record a rapid drop in lake level that Smith and others (1982) interpret as evidence for the time of capture, after which the Snake River drainage was part of the Columbia River system. In the western plain, however, the upper Glenns Ferry Formation floodplain deposits further accumulated in response to continuing graben subsidence. In the late Pliocene the Glenns Ferry Formation was capped by gravels such as the Tennmile Gravel, the last episode of basin filling. This coarsening of sediment deposited in the western Snake River Plain probably was a response to late Pliocene climate change (Othberg, 1994). The changeover from basin filling to incision occurred shortly after the Tennmile Gravel was deposited. Incision initiated the widespread entrenchment and removal of basin deposits and the development of gravel terraces during the Pleistocene (Othberg, 1988, 1994).
Figure 1. Map showing the location of the Boise Valley and the field trip stops within the western Snake River Plain. Contour interval 400 feet.
Figure 2. Distribution of Boise Valley terraces. Lines A-A' and B-B' show the approximate locations of the east and west diagrammatic profiles in Figure 3.
Figure 3. Diagrammatic profiles of the eastern and western Boise Valley terraces and terrace-capping basalt flows. In the western sequence, the Boise, Whitney, and Wilder terraces were mantled with Bonneville Flood sediments; the level of which is indicated. Basalt flows are labeled as follows: MC, basalt of Mores Creek; GT, basalt of Gowne terrace; LP, basalt of Lucky Peak surface; FC, basalt of Fivemile Creek surface; and PR, basalt of Pickles Rim surface.

Figure 4. Stereopair of a block diagram showing the sequence of terraces in the Boise Valley (courtesy of L.R. Stanford, Idaho Geological Survey). A-A' shown for cross reference with Figure 2.
The age of the Tenmile Gravel, and perhaps of the other high-elevation capping gravels of the western Snake River Plain, is constrained by the age of the upper Glenns Ferry Formation and dating of early terrace treads cut into the Tenmile Gravel. Vertebrate fossils and paleomagnetic polarity of the uppermost Glenns Ferry Formation near Marsing (Van Domeelen and Rieck, 1992; Figure 1) suggest that the Tenmile Gravel is younger than the Olduvai Polarity Subchron, which is about 1.76 Ma (Figure 5). A minimum age of 1.58 Ma for the Tenmile Gravel is provided by a radiometric date on the Pickles Butte rim basalt that flowed into an early Pleistocene stream valley (Figures 3 and 5).

At various times in the Pleistocene, basalt flows traveled down the valleys (Figure 6). Radiometric dating and paleomagnetic polarities of these flows have provided numerical ages for the terrace sequence (Othberg and others, 1995; Figure 7). The terrace surfaces are mantled with loess, a wind-blown silt probably derived from floodplains of the Pleistocene Snake and Boise rivers. Soils developed primarily within the loess and show a characteristic increase in development of soil duripans with age (Othberg and Stanford, 1992; and Othberg, 1994). Recent analysis of these soils by Paul McDaniel (this paper) helps confirm the use of duripans in determining the relative age of terraces, and also reveals the complexities of loess deposition and erosion cycles on soil stratigraphy. O'Connor's (1993) study of the Bonneville Flood and the mapping of Bonneville Flood sediment by Othberg and Stanford (1992) have shown that Bonneville slack-water deposits provide a 14.5 ka stratigraphic marker for terrace and soil chronology in the Boise Valley and adjacent Snake River valley.

PLEISTOCENE TERRACES

Each of the gravel terraces of the ancestral Boise River are inset into pre-Quaternary basin-fill sediment. The terrace treads range from 3 meters (youngest) to 150 meters (oldest) above the present river floodplain. The terrace sequence in the Boise Valley is best preserved south of Boise (Figures 3 and 4). The sequence there, in decreasing age, is the Tenmile terrace, the Amity terrace, the Fivemile Creek surface, the Lucky Peak surface, the Gowen terrace, the Sunrise terrace, the Whitney terrace, and the Boise terrace, which lies just above the floodplain of the Boise River.

It has not been possible to trace the Boise Valley terraces into the glaciated headwaters of the Boise River. However, drawing on work by Pierce and Scott (1982), Othberg (1994) makes a case for correlating the Boise Valley terraces in the western Snake River Plain to glacial episodes in the mountains. Othberg (1994) argues that because the Boise River drains both high, glaciated source areas and large areas of

"Surface" is used where the terrace gravels have been completely buried by valley-filling basalt flows.
Figure 5. Correlation of Boise Valley terraces with the glaciations of the northwestern United States and the marine oxygen-isotope cold stages as adapted from Richmond and Fullerton (1986, Chart 1). Ages of the Jaramillo and Olduvai Normal Polarity Subchrons from Cande and Kent (1992). Age of the Cobb Mountain Normal Polarity Subchron from Shackleton and others (1990). Abbreviations for basalt units: MC, Mores Creek; G, Gowen terrace; FC, Fivemile Creek; HR, Hubbard Reservoir; EN, East Nampa; KC, Kuna City; FB, Pickles Butte.
intermediate-elevation mountainous terrain, sustained peak discharges of the ancestral Boise River during glacial episodes may have been at least ten times greater than observed in the river today. The sequence of terraces probably formed during many of the episodes of Pleistocene climate change through repeated periods of downcutting followed by coarse gravel deposition.

The oldest terrace in the Boise Valley, the Tenmile terrace, is composed of the Tennmile Gravel which overlies the late Pliocene, fine-grained, basin-fill locally correlated with the Glenns Ferry formation. Stratigraphically, the Tennmile Gravel is younger than the Glenns Ferry Formation but predates the onset of episodic incision that was typical during the Pleistocene. The upper part of the Glenns Ferry Formation is probably younger than 1.76 Ma, the age of the latest geomagnetic polarity reversal of the Olduvai Normal Polarity Subchron (Van Domelen and Rieck, 1992; Cande and Kent, 1992).

The first known incision into the Tennmile Gravel was at least 68 meters (223 feet) and established the alluvial level probably represented by the Amity terrace in the eastern part of the Boise Valley and the Deer Flat terrace in the western part of the Boise Valley (Figure 3). A minimum age for both the Tennmile terrace and the Tennmile Gravel is the 40Ar/39Ar date of 1.580 ± 0.085 Ma from the valley-rim basalt of Pickles Butte that caps a terrace probably correlative with the Deer Flat or the Amity terraces. The river incision that formed the Tennmile terrace occurred before the Pickles Butte lava flow was emplaced, probably about 1.6 Ma (Figure 5).

All succeeding terrace gravels are younger than the Tennmile Gravel but at least as old as the Bonneville Flood sediment. The latest recorded event of the Pleistocene in the Boise Valley was the Bonneville Flood at 14.5 ka (Scott and others, 1983; Currey, 1990). The catastrophic flood waters were hydraulically ponded behind gorges along the Oregon and Idaho border downstream of Farewell Bend. Fine-grained slack-water sediment was deposited by the ponded waters within the western part of the Boise Valley and similar valleys in the western Snake River Plain. These thin-bedded silts of the Bonneville Flood mantle the inundated, lower three terraces within the western Boise Valley.

The 14,500-year age of the Bonneville Flood provides a minimum date for the terrace sequence and the soil developed on the surface of the Bonneville Flood sediment. Othberg (1994) suggested that the youngest terrace, the Boise terrace, is about the same age as the Bonneville Flood sediment. Evidence from a recent excavation shows Bonneville Flood sediment deposited on the Boise terrace. Near the confluence of the Boise and Snake rivers, the Boise terrace appears scoured by waters of the Snake River that must have postdated deposition of the Bonneville Flood slack-water sediment. These relationships suggest the Boise terrace is a late Wisconsin terrace. Based on the soils developed on the eight terraces and the stratigraphic relationship of the gravels to the Bonneville Flood
deposits and the Glens Ferry Formation, the ages of the terraces in the Boise Valley appear to span the entire Pleistocene.

PLEISTOCENE BASALT ERUPTIONS

During the Pleistocene, basaltic volcanism continued in the western Snake River Plain and in Smith Prairie, northeast of the western Snake River Plain (Howard and others, 1982). The basalts are characterized by subaerial lava flows that formed shield volcanoes, thick canyon fills, and thin flows that spread across broad alluvial valleys. Shield volcanoes, basaltic cones, and lava flows form much of the surface of the western Snake River Plain south and southeast of the Boise Valley. Several of the basalt lavas flowed into the Boise Valley (Figure 6). At least two eruptions of basalt from Smith Prairie flowed 60 km or more down the Boise River canyon and onto the broader alluvial surfaces in the western Snake River Plain. Othberg (1994) describes the sources of these flows and their emplacement on terraces. Howard and Shervais (1973), Howard and others (1982), and Vetter and Shervais (1992) provide stratigraphy, dates, and chemical analyses for basalts that originated in Smith Prairie.

The Boise River canyon near Lucky Peak Dam exposes basalts that bury Pleistocene terrace gravels (Figure 7). All but one of these basalt flows erupted many kilometers upstream and flowed down the canyon and onto the edge of the plain. The early Pleistocene basalt of Fivemile Creek erupted locally, just a few miles from Stop 1.3.

Other basalts flowed into Pleistocene drainageways south of Lake Lowell. Hat, Pickles, Powers, and Kuna buttes were sources for many of these flows (Figure 6). Othberg (1994) surmised that most of the source vents of basalts that flowed down valley(s) ancestral to the present drainage of Indian Creek were to the southeast in the central ridge area of the plain where Christmas Mountain is located (Figure 6). Another possibility is that at least some of the Indian Creek lavas originated in Smith Prairie and flowed as far as 100 km down the ancestral Boise River (Othberg and others, 1995).

Basalt ages range from about 0.1 Ma to 1.58 Ma (Figure 8). Stratigraphic relationships and paleomagnetic polarities corroborate most of the radiometric dates (Othberg, 1994; Othberg and others, 1995). The numerical ages applied to the terraces provide a basis for oxygen-isotope stage correlations (Figure 5).
Figure 6. Locations of selected volcanic vents and flow directions of basalt flows emplaced on terraces of the Boise Valley. C, Christmas Mountain; F, Fivemile Creek; H, Hat Butte; I, Initial Point; K, Kuna Butte; PI, Pickles Butte; PO, Powers Butte; S, Slaters Flat; W, Walters Butte.
Figure 7. Profile and cross section of the Boise River canyon near Lucky Peak Dam showing stratigraphy of lava flows and buried terrace gravels. Stratigraphy of basalt units, oldest to youngest: basalt of Fivemile Creek, basalt of Lucky Peak, basalt of Gowen terrace, and basalt of Mores Creek.

Figure 8. Results of dating of basalts in the Boise Valley and adjoining area. ^{40}Ar/^{39}Ar and K/Ar ages grouped separately. Magnetic polarities of each basalt shown by N or R. Time scales shown for reference. Geomagnetic time scale adapted from Mankinen and Dallymple (1979) as modified by Shackleton and others (1990) and Cande and Kent (1992). Length of vertical age bar shows the precision limit of each date.
SOILS OF THE BOISE VALLEY TERRACE SYSTEM

Pedological studies have greatly contributed to understanding geomorphic relationships in the Boise Valley. Soils of the terrace systems reveal a range in development that reflect the ages of the geomorphic surfaces they occupy. Othberg and Fosberg (1989) and Othberg (1994) suggested that four soil series mapped in the Boise Valley best represent a developmental sequence of late-middle to early Pleistocene soils. From youngest to oldest, these soils are the Power, Purdam, Elijah, and Chilcott series. According to the soil survey of Ada County (Collett, 1980) all have formed in loess or silty alluvium that is underlain by mixed alluvium. Classification and selected characteristics of these soils are presented in Table 1.

Table 1. Classification and selected characteristics of the Power, Purdam, Elijah, and Chilcott soil series.

<table>
<thead>
<tr>
<th>SOIL SERIES</th>
<th>CLASSIFICATION</th>
<th>DIAGNOSTIC FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>fine-silty, mixed, mesic Xeric Haplargid</td>
<td>argillic horizon</td>
</tr>
<tr>
<td>Purdam</td>
<td>fine-silty, mixed, mesic Xeric Argidurid</td>
<td>argillic horizon duripan</td>
</tr>
<tr>
<td>Elijah</td>
<td>fine-silty, mixed, mesic Xeric Argidurid</td>
<td>argillic horizon duripan</td>
</tr>
<tr>
<td>Chilcott</td>
<td>fine, montmorillonitic, mesic Abruptic Xeric Argidurid</td>
<td>argillic horizon abrupt textural change duripan</td>
</tr>
</tbody>
</table>

1 Classifications according to Keys to Soil Taxonomy, 6th ed. (Soil Survey Staff, 1994).
2 Based on series descriptions (Collett, 1980).

This soil sequence illustrates several changes in morphological properties that are time-dependent, including accumulation of layer silicate clays, CaCO₃, and opaline SiO₂. Accumulation of these constituents generally increases with soil age, and as a result, provides a means of assessing relative ages of geomorphic surfaces.

LAYER SILICATE CLAYS

All four soils contain subsurface zones of clay accumulation referred to as argillic horizons (Soil Survey Staff, 1994). Argillic horizon development can be used as a relative indicator of soil age within a given geographic setting (Soil Survey Staff, 1975; Birkeland,
The presence of an argillic horizon implies sufficient landscape stability to allow layer-silicate clays to form as primary minerals weather, and to allow these clays to translocate within a soil profile. Generally, clay accumulation within a soil must be preceded by leaching of CaCO₃ (Duchaufour, 1982). The presence of CaCO₃ maintains colloidal particles in an aggregated or flocculated state; upon removal of CaCO₃, clay colloids become dispersed and can then be more easily transported by water percolating downward through the soil.

Clay accumulation generally increases in soils of geomorphic surfaces with age. Soils of the Whitney terrace such as Power have relatively weakly developed silt loam- to silty clay, loam-textured, argillic horizons. On the other end of the developmental/age sequence, Chilcott soils of the Tenmile surface have strongly developed argillic horizons with an abrupt textural change (relative to the overlying horizon) and silty clay-textures (Collett, 1980; Soil Survey Staff, 1994). Soils of the Sunrise and Gowen surfaces generally exhibit argillic horizon development that is intermediate to that of Power and Chilcott soils.

Using clay accumulation to assess pedogenesis in soils of the Boise Valley is not without problems. Urban development in the area has drastically disturbed the land surface, making it difficult to find suitable sampling locations. Secondly, soils showing different stages of argillic horizon development are commonly mapped together as complexes on the terraces of the Boise Valley. The genesis of these complexes is not well understood, and it may be difficult to determine which developmental stage is "typical" for a given geomorphic surface. Finally, field evidence suggests that multiple cycles of loess deposition, soil formation, and erosion have occurred throughout the Pleistocene. Most geomorphic surfaces, such as the Boise Valley terraces, have experienced more erosion than may have been inferred originally. Thus, some of the described soil horizons may be considerably younger than the geomorphic surface they occupy. Until some of these cycles are better understood, comparison of argillic horizons across geomorphic surfaces must be done cautiously.

**Caco₃ and SiO₂**

Perhaps the most striking feature of Boise Valley terrace soils older than late Pleistocene is the presence of duripans. These duripans are equivalent to caliche layers that have been described throughout the geological and soil science literature. However, designating a soil horizon as a duripan implies a greater specificity of properties and processes than does the use of the term caliche. A duripan is defined by Soil Taxonomy as "a subsurface horizon that is cemented by silica to the degree that fragments from the air-dry horizon do not slake during prolonged soaking in water or in HCl" (Soil Survey Staff,
1975). By definition, duripans are primarily cemented by opaline SiO₂ in contrast to petrocalcic horizons that are primarily cemented by CaCO₃ (Soil Survey Staff, 1994). In the arid and semiarid environments of southern Idaho, the compositions of most cemented pans undoubtedly lie somewhere between pure SiO₂ and CaCO₃ end members. Duripans are more abundant in southwestern Idaho while petrocalcic horizons appear to be more abundant in southeastern Idaho.

Duripan formation generally requires a source of relatively soluble SiO₂ in addition to the presence of CaCO₃ (Soil Survey Staff, 1975). In many areas where duripans are extensive, volcanic glass serves as this source (Chadwick and others, 1987; Chadwick and others, 1989). Volcanic glass is not readily apparent as a component of loess in southern Idaho, and research suggests that the recycling of biogenic SiO₂, and the emplacement of loess may be more important than volcanic glass in duripan formation (Blank, 1987; Blank and Fosberg, 1991).

Duripans provide an excellent means of assessing pedogenesis because of their physical and chemical properties. After some initial stage of development has been attained, duripans become resistant to subsequent weathering and erosion. This may be important in an area like the Boise Valley where cycles of erosion have apparently removed other, less-stable products of pedogenesis. Under these conditions, it seems reasonable to expect that the age of a characteristic duripan, which resists erosion, will more closely match the age of a geomorphic surface than will the pedogenic development of the overlying, less resistant soil horizons.

Accumulation of CaCO₃ in soils has been extensively used by geologists and soil scientists as a relative dating tool in arid and semiarid landscapes of the western U.S. (Gile and Grossman, 1979; Machette, 1985; Harden, 1982; Reheis and others, 1989). Our research in the Boise Valley area supports the trend of increasing CaCO₃ accumulation in soils of increasing age that has been reported by other researchers. We examined CaCO₃ content of duripans from the Whitney, Sunrise, Gowen, and Tennmile surfaces (Figure 9). Data are presented for the geomorphic surfaces rather than for specific soils because of the difficulty in locating undisturbed soil profiles that correspond to known soil series. The CaCO₃ accumulation index reflects the average CaCO₃ equivalent of each duripan multiplied by a relative depth factor. For example, the thickest duripan (Tennmile surface) is assigned a depth factor of 1.0, other duripans are assigned a factor based on their thickness relative to that of the Tennmile duripan.

Despite the abundance of work using CaCO₃ accumulation as an indicator of pedogenesis, surprisingly little research has quantified SiO₂ accumulation as a function of soil age. We measured opaline SiO₂ in duripans of the Pleistocene surfaces in the Boise Valley using the Tiron extraction procedure described by Kodama and Ross (1991; Figure
Comparison with Figure 9 suggests that accumulation rates of both SiO$_2$ and CaCO$_3$ have been greatest in soils occupying the middle Pleistocene-age surfaces (Whitney, Sunrise, and Gown). Furthermore, little additional accumulation of SiO$_2$ and CaCO$_3$ has occurred in soils of the early Pleistocene Tenmile surface.

Figure 9. CaCO$_3$ equivalent index for duripans in the Boise Valley occupying different-aged geomorphic surfaces. Index is calculated by multiplying average CaCO$_3$ equivalent by a duripan thickness factor. W = Whitney surface; S = Sunrise surface; G = Gown surface; and TM = Tenmile surface.

Figure 10. Opaline SiO$_2$ index for duripans in the Boise Valley occupying different-aged geomorphic surfaces. Index is calculated by multiplying average opaline SiO$_2$ content by a duripan thickness factor. W = Whitney surface; S = Sunrise surface; G = Gown surface; and TM = Tenmile surface.
OVERVIEW OF THE BONNEVILLE FLOOD STORY

GENERAL SETTING AND CHRONOLOGY

The Bonneville Flood resulted from the filling and the consequent spill-over of Pleistocene Lake Bonneville into the Snake River drainage about 14.5 ka. About 4750 cubic kilometers of water was released near Red Rock Pass, Idaho, and traveled down the present courses of Marsh Creek and the lower Portneuf River before entering the Snake River Plain north of Pocatello. For the most part, the flood route followed the present westward course of the Snake River within the Snake River Plain through a series of canyons and basin segments before turning north and entering the narrow and deep Hells Canyon along the Idaho-Oregon boundary. At Lewiston, the Snake River turns abruptly to the west and enters the Columbia River near Pasco, Washington. The scope of the study by O'Connor (1993) was restricted to the area upstream of Lewiston (Figures 11 and 12).

LAKE BONNEVILLE

During the latest Pleistocene, Lake Bonneville was the largest of numerous lakes located within the closed basins of the Basin and Range province of western North America (Benson and Thompson, 1987). At its highest level Lake Bonneville covered 51,530 km² in western Utah and parts of Nevada and Idaho. As reported by Currey (1990), during its last cycle, Lake Bonneville began to rise episodically from about 28 ka until it reached its maximum Bonneville level at about 15.2 ka (Figure 13). At levels below the Bonneville shoreline complex (1552 m (5102 feet) near Red Rock Pass), the lake had no outlet and the water level was controlled by the balance between precipitation and evaporation. When the lake surface reached an altitude of 1552 m (5092 feet), it met the lowest of the divides between the Bonneville Basin and the watershed of the Snake River, near Red Rock Pass, Idaho, and began to drain to the north (Gilbert, 1878, 1890). Lake Bonneville was apparently maintained at an altitude near 1552 m (5092 feet) for several hundred years until about 14.5 ka (Scott and others, 1983; Currey and others, 1990).

5Modified from O'Connor (1993).

4All chronologic information presented here was reported and compiled by Currey and his associates [see Currey (1990) for a review] and was based on radiocarbon dates on materials that can be stratigraphically linked to shoreline features in the Bonneville basin.

7 A note on units: because all original mapping and flow modeling was performed with English-unit maps (U.S. Geological Survey 7.5' Quadrangles), all altitudes are reported in both metric and English units; all other measurements are reported only in metric units.
Figure 11. Map of the Bonneville Flood route and approximate area of inundation between Red Rock Pass and Lewiston. From O'Connor (1993).

1983a; Currey and Oviatt, 1985; Currey, 1990) (Figure 13). This provided enough time for the prominent Bonneville shoreline complex to develop and for the short regression between 15.0 ka and 14.5 ka [the Keg Mountain oscillation of Currey and others (1983b)].

At about 14.5 ka, conditions at the outlet changed and rapid incision began, resulting
Figure 12. Profiles of the Snake River, Portneuf River, and Marsh Creek with evidence of maximum Bonneville Flood stages. The altitudes plotted here are minimum estimates of measured altitudes for flood features. The Bonneville Flood profile was stepped with much of the water-surface drop over short distances separated by long reaches of more quiescent flow. Evidence for maximum stages in the Eden channel (north of the Snake River) is not shown. From O'Connor (1993).

in a 108 m drop of the lake-level before the outlet stabilized at an altitude of 1444 m (4738 feet). The lake remained at this level (the Provo level), with continued overflow into the Snake River drainage, until about 14.2 ka when the lake rapidly regressed to Holocene levels similar to that of the present-day Great Salt Lake (Scott and others, 1983; Currey and others, 1983a; Currey, 1990).
Figure 13. Generalized late Pleistocene history of lake levels in the Lake Bonneville basin between 30 ka and 10 ka as shown in O'Connor (1993). The only time of open-basin conditions was while the lake was at the Bonneville and Provo levels. Subsequent to stabilization at the Provo level after the Bonneville Flood, changing climatic conditions resulted in rapid desiccation to levels similar to the present Great Salt Lake. After Currey (1990).
HYDRAULICS OF THE BONNEVILLE FLOOD BETWEEN SWAN FALLS AND FAREWELL BEND

SWAN FALLS TO MARSING

The Swans Falls reach extends from the Swan Falls constriction, upstream of Swan Falls, to the town of Marsing (Figure 14). This reach is the most downstream portion of the flood route studied by Malde (1968, p. 42-44). Using highwater evidence near the Swan Falls constriction, previous discharge estimates for the Bonneville Flood have been calculated (Clifford Jenkins, in Malde, 1968, p. 11-12; Jarrett and Malde, 1987). This reach of the Snake River encompasses the morphologic transition between an incised canyon within Snake River Plain basalt flows and the wide, low-gradient, alluvial basin that the river follows before turning north and entering the gorges along the Oregon-Idaho border.

Within the Swan Falls constriction and the narrower canyon segments there are no flood deposits and the canyon walls are devoid of talus. However, in wider reaches, there are extensive longitudinal and expansion bars. The bars immediately downstream of the constriction (the bars near Priest Ranch) have abundant, well-rounded boulders exposed on the surface with maximum diameters exceeding ten meters. Further downstream, the Initial Point and Walters Butte bars (Figure 14) are large deposits of material eroded from the narrower canyon segments. At the downstream end of the reach, flow was less energetic and primarily deposited sand and gravel.

Jarrett and Malde (1987) reported an important high-level flood deposit immediately upstream of the Swan Falls constriction. This small bar, at an altitude of 829 m (2719 feet), and a nearby eroded basalt surface with a maximum altitude of 840 m (2755 feet), provide minimum constraints for the maximum flood stage upstream of the constriction. Downstream evidence indicates that the profile dropped quickly through the constriction and the narrow canyon segments below, to an altitude of 783-796 m (2570-2590 feet) near the upstream end of Walters Bar and to 762-768 m (2500-2520 feet) at the downstream end of the reach (Figure 15).

Flow profiles were calculated using HEC-2 through 106 cross sections representing the 60 km reach. A minimum discharge of 0.82 to 0.85 x 10⁶ m²/sec⁴ gives a calculated profile consistent with most of the geologic evidence of maximum stages over the length

⁴HEC-2 is computer program developed by the Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.
Figure 14. Map of Bonneville Flood features and inundated area for a portion of the Swan Falls reach. The modeled reach extended several kilometers downstream of the mapped area to Marsing. Some aspects of the geology are modified from Malde (1989a, b). From O'Connor (1993), the reach and, most importantly, results in an appropriate water-surface altitude upstream of the Swan Falls constriction with respect to the flood features identified by Jarrett and Malde (1987). The calculated profile is stepped through the upper part of the reach with the three major drops all occurring at constrictions. The largest fall in the water surface was probably at the Swan Falls constriction, where the modeled profile drops about 25 meters. Critical or supercritical flow conditions were calculated for the Swan Falls constriction and at the constriction immediately upstream of Walters bar (Figure 15).
Jarrett and Malde (1987) used a step-backwater computer program similar to HEC-2 to obtain an estimate of $0.793 \times 10^6 \text{ m}^3\text{sec}^{-1}$ for peak discharge through the Swan Falls constriction. Considering several factors, including possible widening of the constriction during the flood, they proposed that a discharge of $0.935 \times 10^6 \text{ m}^3\text{sec}^{-1}$ is a most likely estimate for peak discharge. For model runs with hydraulic parameters similar to those used in this study, they estimated a discharge of $0.99 \times 10^6 \text{ m}^3\text{sec}^{-1}$, 15 to 20% greater than the $0.82-0.85 \times 10^6 \text{ m}^3\text{sec}^{-1}$ estimate of peak discharge obtained in this study. Part of the discrepancy may be the result of using different sets of cross sections to characterize the channel geometry. However, it more likely relates to the strategy of this study which was to define a minimum estimate of peak discharge. For the Swan Falls reach, where flow had high velocities near the important highwater evidence, the stage evidence is compared to the energy-surface profile, instead of the calculated water surface.
profile, because of possible runup effects (Figure 15).

Downstream of Marsing, the flood followed the low-gradient valley of the Snake River and backflooded several tens of kilometers up the major tributaries that enter the Snake River before entering the gorges downstream of Farewell Bend (Figure 11). Extensive fine-grained flood deposits (slack-water sediment) are found in the valleys of the Boise (Othberg and Stanford, 1992; Othberg, 1994), Payette, and Owyhee Rivers. The flood profile dropped very little through this reach; water was apparently ponded to an altitude of at least 746 m (2447 feet) behind the constriction near Farewell Bend (Figure 12).

FAREWELL BEND

The constriction at Farewell Bend is located where the Snake River enters the series of gorges that the river follows along the Oregon-Idaho and Washington-Idaho borders (Figure 16). Downstream of Farewell Bend, preserved flood deposits are sparse and maximum stage evidence is difficult to discern confidently. This is partly due to the narrowness of the flood route, but is primarily the result of the extremely steep and active slopes along the margins of the gorge. Calculating water-surface profiles for the Farewell Bend reach was done for the sole purpose of obtaining a discharge estimate associated with erosional features upstream of the constriction at Farewell Bend that indicate a minimum ponding level of 746 m (2447 feet) at peak discharge.

Flow was modeled using 68 cross sections over a distance of 50 km. A water-surface profile associated with a discharge of $0.65 \times 10^4 \text{ m}^3\text{sec}^{-1}$ results in a ponding level behind the constriction consistent with the altitudes of the highest flood features (Figure 17). A discharge of $0.82 \times 10^4 \text{ m}^3\text{sec}^{-1}$ results in a predicted ponding level of 760 m (2494 feet), the maximum stage at the downstream end of the Swan Falls reach, and probably provides a reliable upper limit for an estimate of the discharge that entered the Farewell Bend reach.
Figure 16. Major flood deposits and the inundated area near Farewell Bend. From O'Connor (1993).
Figure 17. Geologic evidence of maximum stages and calculated profiles for the Farewell Bend reach. A discharge of 0.65 million m$^3$ sec$^{-1}$ results in a calculated water-surface profile that matches or exceeds all of the high water evidence. A discharge of 0.82 million m$^3$ sec$^{-1}$ results in a calculated water-surface profile consistent with the evidence of the maximum stage at the downstream end of the Swan Falls reach. From O'Connor (1993).
DESCRIPTION OF FIELD GUIDE STOPS

The field guide stops are also organized according to the two themes, the Boise Valley terraces and the Bonneville Flood. On the first day the terraces and terrace soils are viewed, and on the second day the Bonneville Flood features are observed.

Day one covers the older part of the Quaternary geology that is primarily exposed in the southeastern area of the Boise Valley. The trip begins at Bonneville Point, a historic site and a vista from which one can see from one side of the western Snake River Plain to the other. From there, the field trip stops drop down in elevation and decrease in age, revealing the story of the terrace sequence and soils.

The second day of the field trip begins at Centennial Park, a Canyon County park located on the Snake River at Guffey Bridge. So much can be seen and studied near this park that about two hours is allowed for the first stop. From there the trip roughly follows the Snake River downstream to near the confluence with the Boise River, and then beyond almost to the confluence with the Payette River.

DAY ONE

Road Log and Stop Descriptions (mileage is approximate).

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**Route to Stop 1.1:** Drive east from Boise on I-84 (Figure 1). The rest area near mile post #63 is an opportunity for rest rooms before Stops 1.1 and 1.2. An additional stop at this rest area is possible after leaving Stop 1.2. After the rest area, take the Blacks Creek exit (#64). Turn left and go through the underpass, following Blacks Creek Road northeast toward the mountains. Turn left on a gravel road at the historical site sign. The road climbs a hill toward a microwave facility. Follow the main road, turning left away from the microwave facility and toward the historical site. Park in the loop next to the fenced site.

0.0 0.0 **STOP 1.1: Bonneville Point Historical Site.** This is the high-elevation point of a branch of the Oregon Trail, named after Lieutenant Bonneville who is credited with first applying the word Boise ("woods" or "trees") from this spot where he could see the Cottonwoods on the river floodplain below. From this vantage one can see several features of the foothills, some
of the terraces, and when visibility is good, the volcanoes of the central ridge of the western Snake River Plain and the Owyhee Mountains on the opposite side of the plain.

This broad ridge is composed of the gravel of Bonneville Point (Othberg, 1994). The gravel was originally included in the Payette Formation by Lindgren (1898), who recognized that it represents facies of the ancestral Boise River. The gravel of Bonneville Point is composed of clasts of granitic rocks and porphyritic felsites from the central Idaho mountains. This contrasts with the near-source, dominantly granodioritic composition of the Boise foothills Idaho Group. Savage (1958) included the gravel of Bonneville Point in the Tenmile Gravel, but because of differences in stratigraphy, weathering, and depositional settings, a separate name seemed warranted (Othberg, 1986; Othberg and Burnham, 1990; Othberg and Stanford, 1992; Othberg, 1994). Exposures within a long washout gully on this side of Lydle Gulch show that the gravel of Bonneville Point is composed of interbeds of channel gravel and sand with common depositional breaks represented by buried soils. The color of this unit is characteristically yellow-orange, due to considerable weathering and release of iron oxide. In many locations as much as half of the gravel clasts have been softened by weathering.

The gravel of Bonneville Point forms the Bonneville Point upland, an east-west ridge that steps downward to the west and southwest along faults (Othberg and Stanford, 1992; Othberg, 1994). Its high point lies to the east beyond Lydle Gulch at an elevation of about 1,256 meters (4,120 feet), some 98 meters (321 feet) above the historical site. As noted at Stop 1.1, the gravel caps hills on the north side of Lucky Peak Dam where its highest elevation is also about 1,256 meters (4,120 feet). East of the high remnants of gravel, one can see the irregular topography of weathered Idaho batholith. The gravel of Bonneville Point once formed a river lowland bordered by hills of granodiorite. Rocks of the batholith eroded more quickly than the gravel. This ridge of gravel is, therefore, an example of reversed topography caused by the gravel's greater resistance to erosion.

The gravel of Bonneville Point is at least 152 meters (500 feet) thick and may be over 244 meters (800 feet) thick under the Oregon Trail site on the downthrown side of the Lydle Gulch fault. The gravel on the other side of Lydle Gulch is about 91 meters (300 feet) thick, and tapers rapidly to the east where it makes an 24-meter (80-foot) thick cap under the 1,256 meter (4,120 foot) ridge top. The great change in thickness suggests the ancestral
Boise River was filling the edge of the plain as it was dropping along the range-front fault.

To the northwest, Table Rock rises above the city. Table Rock, an erosional remnant, is composed of near-shore Lake Idaho sands that have been cemented by silica-rich geothermal water. On the west side of Table Rock lies Warm Springs Mesa, a bench area formed by movement of an ancient landslide—probably the largest example of many landslides known to exist in the foothills (Beck, 1989; Othberg and Burnham, 1990; Burnham and Wood, 1992).

The view toward the west side of Boise shows the broad bench areas across which the city has spread. The lower benches consist of two terraces of the Pleistocene Boise River—the Whitney and Sunrise terraces (Figures 3 and 4) (Othberg and Stanford, 1992; Othberg, 1994), that are described in Stops 1.4 and 1.5.

Aircraft may be seen from here on final approach into Boise International Airport. The airport rests on the Gowen terrace (Figures 3 and 4), which will be described in more detail at Stop 1.3. Between here and the airport is the Micron computer chip manufacturing plant and the large south Boise water tower. They are on the surface of the basalt of Fivemile Creek (Figures 6 and 8), which erupted from a fault-line gully in the Bonneville Point upland just south of Micron and east of I-84.

To the west the slope of the Bonneville Point upland flattens where it grades into the Tenmile terrace (Othberg and Stanford, 1992). Remnants of this early terrace, composed of the Tenmile Gravel, extend west to the Snake River. Stop 1.2 describes the Tenmile terrace and the Tenmile Gravel.

Farther to the west and southwest, several volcanoes of the graben’s central ridge of volcanic vents can be seen on a clear day. These include Kuna Butte, Powers Butte, Initial Point, and Christmas Mountain. The more recent volcanoes, as young as about 400,000 years (Othberg, 1994; Othberg and others, 1995), are some of the latest vestiges of the tectonic and volcanic activity that created the rift basin. The Owyhee Mountains rise above the southwest-bounding fault zone of the graben (Figure 1), completing the view across the Western Snake River plain.

1.4 Leave the historical site and drive back to Blacks Creek Road. Note the
well-developed patterned ground. The weathered surface of the gravel of Bonneville Point is characterized by round to oblate mounds 4-6 meters in diameter with nearly equal spacing between the mounds. The mounds are composed of silty soil. The upper part of the gravel, which is exposed between the mounds, is highly oxidized and partly cemented. The patterned ground may have developed during periods of Pleistocene periglacial conditions (Malde, 1964).

THE TERRACE SEQUENCE

6.1 4.7 Turn right on Blacks Creek Road and drive west. Go through the I-84 underpass and continue to the stop sign at the railroad crossing.

Either park or turn right and follow a primitive four-wheel track one-half mile northwest. Blacks Creek is usually easy to ford and typically is dry in the summer and autumn. Park at the base of the escarpment. Warning: Beware of rifle target practicing in this area! Let the shooters know you are present! Follow the primitive road on foot about 400 meters, then cross the barbed-wire fence to enter the railroad grade.

STOP 1.2: Tenmile terrace soil—Blacks Creek railroad grade. The surface of the Tenmile terrace has been cut by many parallel faults with a net displacement down toward the center of the basin. Numerous ravines dissect the sides of the terrace and follow the trends of faults. Thin loess generally mantles the gravel and a well-developed patterned ground is present but is most apparent from an aerial view. Soils on relatively stable surfaces have formed thick duripans over the 1.6 million years since the Tenmile Gravel was deposited (Othberg, 1994).

Chilcott and Sebree soils occur as a complex on this part of the Tenmile terrace. Here, both soils formed in loess and have a clayey argillic Bt horizon overlying a thick, well-developed duripan. The duripan exposed at this stop is as much as 1 meter thick and contains the greatest amount of CaCO₃ and SiO₂ of any of the duripans in the Boise Valley. Despite the large quantity of CaCO₃, prolonged soaking of several duripan samples in HCl had little effect on their integrity, suggesting opaline SiO₂ is the cementing agent. The duripan is also characterized by the presence of several continuous laminae composed primarily of opaline SiO₂. This degree of duripan development would be equivalent to the stage IV carbonate accumulation described by Gile and others (1966) in the desert Southwest. Dominant morphology of the duripan is that of thick plates,
with thicknesses ranging between 20 and 50 mm.

To the south, the surface of the basalt of Slaters Flat forms the horizon. The basalt erupted about 1 million years ago (Figure 7) and flowed down the ancestral Blacks Creek, which had already incised its valley into the Tenmile Gravel.

East of here is the Idaho State Penitentiary and the Pleasant Valley Road, where faulting is exposed in the Tenmile Gravel. The Tenmile Gravel in the road cut has the gray color, coarse texture, and crude bedding characteristic not only of this deposit but of all the terrace gravels in the eastern Boise Valley. The main feature at this site, however, is an exposure of several meters of offset on one of the northwest-southeast faults common in this gravel ridge. Many of the faults show movement down on the southwest side, but some, like this fault, are antithetic to the graben boundary fault and show movement down on the northeast side. Here, the northeast side of the fault was filled with loess, presumably as a fault scarp episodically formed. Thin calcic and duripan horizons in the loess may represent relatively long periods of stability between fault movements and loess deposition. No scarp appears at the surface today, suggesting that movement on the fault ceased long ago. Several faults have been exposed in active gravel pits along Pleasant Valley Road. All of these exposed structures strike northwest-southeast and show a few meters of movement down to the southwest. A major fault zone lies a few miles west of here along which Tenmile Creek has cut across the older terraces (Othberg and Stanford, 1992). In addition to the range-front fault zone that forms the border between the plain and the foothills in Boise, distinct, parallel fault zones reflect some of the subbasin movements within the graben (Wood, 1981; Othberg and Stanford, 1992; Othberg, 1994; Wood, 1994). Othberg (1994) measured terrace gradients and estimated postdepositional tilting of the terraces with respect to the present river valley. The results supported Wood's (1981) interpretation of the Nampa-Caldwell subbasin. The eastern Boise Valley terraces have been tectonically tilted toward the subbasin, showing an increase in original gradients with age. West of the subbasin, the terraces show a flattening of gradient with age. Faulting and subsidence appear to have been active throughout most of the Pleistocene. However, no evidence of tilting or faulting has been observed in the Whitney terrace and younger surfaces (Othberg, 1994).

The terraces of the eastern Boise Valley have several features in common. First, the gravel deposits of all the terraces are very similar in texture,
sorting, and bedding. Second, prior to aggrading the valley bottom with coarse gravel, the river cut down into the older, Tertiary basin-fill deposits. In this area south and southeast of Boise, the basin fill consists of the gravel of Bonneville Point, representing the facies of the ancestral, late Tertiary Boise River. These pits show the Tenmile Gravel overlying the gravel of Bonneville Point. The Tenmile Gravel is less weathered and generally coarser grained than the underlying more weathered, generally finer grained and finer bedded gravel of Bonneville Point. The suite of gravel clasts, representing the plutonic and volcanic rocks in the headwaters of the Boise River, is the same in the gravel of Bonneville Point and the Tenmile Gravel. This similarity is distinctive compared with the younger terrace gravels that additionally contain a 10 percent component of basalt clasts derived from Pleistocene lavas erupted in the Boise River drainage. The change in lithology provides a limiting age which helps confirm that the Tenmile Gravel was deposited near the end of the Pliocene about 1.7 Ma (Othberg, 1994).

8.6  2.5  Return to Blacks Creek Road. Turn left and retrace route under the freeway to the I-84 onramp.

9.6  1.0  Enter the freeway and drive west toward Boise on I-84 to the Interstate rest area. The rest area is the last rest room facility available before the lunch stop.

Continue west on I-84, descending from the high ridge of gravel onto the surface of the basalt of Fivemile Creek (Figure 2). This lava flowed into the floodplain of the ancestral Boise River (at this time still flowing west) and followed the valley bottom downstream to the vicinity of Tenmile Creek. The river was forced to shift its channel to the northern edge of the lava flow. The gravel of the buried floodplain is exposed only in a few excavations. One notable site is the Federal Way road cut near a Simplot Building.

14.8  5.2  Idaho City/Gowen Road/ID 21 (Exit 57). Exit I-84 and turn right on Gowen Road.

15.3  0.5  Traffic light at Federal Way. Turn left and drive north.

15.6  0.3  The Simplot Building is ahead on the right as the road begins a descent to the Gowen terrace. Drive slowly past the road cut, which exposes a single, 3-4 meter thick basalt flow. Near the bench escarpment gravel is visible
under the basalt. The top of the gravel, which has been baked a reddish orange color, lies near a bench mark with an elevation of 2,989 feet. This is the lava-buried surface of the sixth terrace above the Boise River (Othberg, 1994). The basalt of Fivemile Creek has a K/Ar date of about 974,000 years (Othberg and others, 1995). Based on normal paleomagnetic polarity, it probably erupted during the Jaramillo Normal Polarity Subchron about 1 million years ago. The terrace gravel buried by the basalt contains clasts of Pleistocene basalt. These clasts were probably derived from the Steamboat Rock Basalt, which is older than the basalt of Fivemile Creek and was erupted in the Smith Prairie area (Othberg and others, 1995).

16.0 0.4 Continue north down onto the Gowen terrace. Just after crossing the railroad tracks, park along the broad shoulder or in one of the parking lots of the industrial area to the right.

STOP 1.3: Gowen terrace—railroad grade parallel to Federal Way. Walk west across Federal Way at Yamhill Road and follow the railroad tracks as they curve northward toward a long cut that exposes the gravel of Gowen terrace. The escarpment of the basalt of Fivemile Creek surface is visible to the south. Exposures west of Federal Way show the basalt overlying a terrace gravel. Barely visible on the skyline is the Tenmile terrace. To the east the Boise foothills, Aldahe Summit, and Boise Peak form the skyline. Table Rock is the prominent mesa in the foothills. The foothills are composed of Tertiary basin-fill sediment, basalt and rhyolite flows, and basaltic tuffs. The Idaho batholith underlies the Tertiary rocks and composes the mountainous terrain. Visible to the north, a remnant of the Sunrise terrace lies just below this site. In the distance, housing developments and downtown Boise cover the Boise terrace. To the northwest the old Union Pacific Railroad Station tower is on the Whitney terrace, which forms the main bench of the greater Boise metropolitan area.

The Gowen terrace is the fourth terrace above the Boise River. When it was the ancestral Boise River's floodplain, the river was still flowing roughly westward after going around the basalt of Fivemile Creek. The next highest (seventh) terrace, buried by the basalt of Lucky Peak, is only known to exist in the canyon area between here and Lucky Peak Dam. Gravel pits in the Gowen terrace near this site have shown that the gravel of Gowen terrace was deposited on a surface cut into the gravel of Bonneville Point. However, further northwest these gravels and those of younger terraces were deposited on finer grained facies of the basin fill.
(Squires and others, 1993; Othberg, 1994). The age of the Gowen terrace is best estimated by the thick duripan (Figure 7) and dating of the basalt of Gowen terrace. The basalt probably erupted in Smith Prairie and flowed downstream onto this surface to a point about one-half mile east of this railroad grade. A K/Ar date of about 575 ka is consistent with the basalt’s normal paleomagnetic polarity and the development of a thick duripan. The large precision error for the K-Ar date encompasses the period of oxygen isotope stages 12-18, or the early part of the Brunhes Normal Polarity Chron. Stratigraphically, the terrace gravel buried by the normal polarity basalt of Lucky Peak is older than the gravel of Gowen terrace, but younger that the Brunhes-Matayuma boundary. This suggests a broad correlation of the Gowen terrace with oxygen isotope stages 12 and 14, or an age of about 500 ka (Othberg, 1994).

The dominant soil at this stop is the Elijah series, which formed in loess. There are no undisturbed exposures of the upper part of the soil at this stop, but the Bt horizon is argillic, characterized by a heavy, silty clay loam. Thickness of the duripan exposed in the railroad cut averages 0.6 meter; average depth to the top of the duripan is 0.9 meter. Quantities of CaCO$_3$ and opaline SiO$_2$ are slightly less than those in the Tenmille terrace; plates of duripan material range between 10 and 20 mm. Rounded gravels can be observed on top of the duripan at this site, indicating an unconformity between the modern soil and the duripan.

Drive north on Federal Way and descend onto the Sunrise terrace.

16.8 0.8 Intersection with Amity Road (ID 21). Turn right and drive east.

17.6 0.8 The basalt of Gowen terrace can be seen on the escarpment on the right. This is about its furthest downstream extent.

18.6 1.0 In the distance on the right is the Boise River canyon where three canyon-filling lava flows can be seen. In age sequence and by altitude above the river, they are the basalt of Fivemile Creek, the basalt of Lucky Peak, and the basalt of Gowen terrace.

19.0 0.4 Turn left before the bridge and enter Barber Park. Possible lunch stop.

22.7 3.7 Retrace route to Federal Way. Turn left and drive south to the intersection with Gowen Road.
27.3 4.6 Turn right on Gowen Road and drive west passing under I-84 and past the Idaho National Guard facilities. Turn left half way through the curve to continue on Gowen Road (the main road curves right to go around the end of the airport).

29.3 2.0 Turn left on Curtis Road and drive 200 feet to a stop sign. Turn left on West Victory Road.

30.3 1.0 Turn right onto Cole Road.

30.8 0.5 Turn right at the first road into the industrial park.

31.1 0.3 Drive east to the entrance of the gravel pit. Enter the pit and follow the paved road to the office building in the center of the pit. With permission from the office personnel, drive or walk to the south pit wall. This pit is largely inactive. It is used for a dumping ground (obviously) and is being filled. Beware of hazards!

**STOP 1.4: Cole Road and I-84 gravel pit.** This gravel pit was dug into the Sunrise terrace, the third terrace above the Boise River floodplain. The terrace gravel and its loess mantle can be seen in the pit walls, and the unconformable, river-cut surface of the Tertiary basin-fill sand can be seen in the bottom of the pit. In places, faults cut the Tertiary sands. One fault cuts the lower part of the terrace gravel (Othberg and Burnham, 1990). The rim of the pit exposes a duripan less developed than that on the Gowen terrace. No radiometric dates are available for this terrace, but Othberg (1994) suggested a correlation with oxygen isotope stage 8 or 10, placing the time of gravel deposition at roughly 300 ka.

Good exposures of the modern soils at this site have been eliminated by excavation and grading. The duripan exposed in the pit headwall, however, has characteristics associated with the Purdam soil. A fairly continuous, thin laminar cap (1-2 mm thick) that averages 0.5 meters in thickness is present in the upper part of the duripan. Although the opaline SiO₂ content of the duripan is comparable to that of the Gowen and Tenmile duripans, the degree of SiO₂ cementation is considerably less. CaCO₃ appears to be more important as a cementing agent in this soil. Before the overlying soil was removed, depth to the duripan averaged 0.5 meter. Some rounded gravels are present on top of the duripan, and a paleosol has developed between the duripan and the underlying gravels.
31.9 0.8 Return to Cole Road. Turn left and drive south to Victory Road.

35.9 4.0 Turn right on Victory Road and drive west to Eagle Road and a highway sign for I-84. Victory Road closely follows the edge of the Sunrise terrace just below the escarpment of the Gowen terrace (on the left). In this area the terraces have been offset by faults within the Tenmile Creek fault zone (see Othberg and Stanford, 1992).

Turn right on Eagle Road and drive north across I-84.

37.9 2.0 Intersection of ID 55 and Franklin Road. The highway drops through the escarpment of the Sunrise terrace and descends onto the Whitney terrace, the broadest surface and the main bench in the Boise-Meridian area.

42.0 4.1 Intersection of ID 55 and US 20. The highway is cut through the escarpment of the Whitney terrace and descends onto the Boise River floodplain. The highway then crosses the southwest branch of the Boise River.

43.4 1.4 On the right is the entrance to a residential area built on Eagle Island, which is part of the floodplain of the Boise River. It was most recently flooded about ten years ago. The highway continues toward Eagle, crossing the northwest branch of the Boise River, and then rises slightly onto the Boise terrace.

44.3 0.9 City of Eagle and the intersection of ID 44 and ID 55. Turn right and drive east on ID 55. The highway lies on the Boise terrace.

46.5 2.2 Traffic light where ID 55 turns north. Turn left and drive north. Ahead, the escarpment of the Whitney terrace rises above the Boise terrace.

47.2 0.7 At the escarpment, turn left on Hill Road (watch for traffic). Park on the shoulder of Hill Road next to a large gravel pit. This pit has had many good exposures but is so active that it changes all the time. Permission to enter can be obtained from the office at the east end, upper level of the pit. Caution! The pit walls are extremely steep and prone to caving and raveling. Stay away from the most recent excavations!
STOP 1.5: Whitney terrace—Hill Road and ID 55 gravel pit. The Whitney terrace is present on both sides of the Boise River. To the south, the Boise terrace is in view from Hill Road to somewhat past ID 55. The Boise River floodplain is beyond the dense cottonwoods in the distance. Further south, the Hewlett Packard building rises above the bluff of the Whitney terrace. On the horizon is the Tenmile terrace.

This gravel pit provides one of the best exposures of the gravel of Whitney terrace. The floor of the pit is close to the contact with Tertiary, Idaho Group, basin-fill silt and sand. Toward the foothills the surface of the gravel is covered with sandy alluvial fan deposits. The mainstream gravel exposed here probably interfingered with sandy sidestream deposits reworked from Tertiary sediment in the local foothills.

In the Boise River canyon near Lucky Peak Dam, the basalt of Mores Creek lies somewhat lower than the Whitney terrace but above the Boise terrace. A K/Ar date of about 107 ka for this basalt provides a minimum age for the Whitney terrace. Othberg (1994) suggested a broad correlation of the Whitney terrace with the Bull Lake Glaciation or oxygen isotope stage 6.

The Power and Purdam soil series are exposed in this pit. These two soils form a complex pattern of soil development on the surface of the Whitney terrace. At least two or three paleosols have formed in ~2.5-meter thick loess that overlies the stream gravels at this site. A relatively weak, laterally discontinuous duripan is also exposed. Purdam soils are associated with the duripan and occur in a complex with Power soils, which are more weakly developed and do not have a duripan. The duripan at this site is the most weakly developed of those in the Boise Valley. It does not have a continuous laminar cap and would be equivalent to the stage III carbonate accumulation described by Gile and others (1966); CaCO₃, and opaline SiO₂ contents of this duripan are considerably less than those of the older terraces. A strongly developed paleosol Bt horizon overlying the duripan can be seen in the pit headwall. The presence of paleosols suggests the occurrence of multiple loess deposition and soil formation cycles since the gravel of Whitney terrace was deposited.

END OF DAY 1
DAY TWO

MILE  DESCRIPTION
cum.  diff.

**Route to Stop 2.1**: Drive to Nampa on I-84 and turn on Exit 36 (Franklin Road) going south into Nampa. Follow Franklin Road and 11th Avenue into the center of Nampa. Then follow the signs for ID 45 (Murphy) and drive south about 17 miles to Walters Ferry at the Snake River. Turn left on Ferry Road (about one-quarter mile before the bridge at Walters Ferry) and drive 2 miles to Hill Road. Turn right and follow Hill Road 2.3 miles to Sinker Road. Turn right on Sinker Road, an old railroad grade, and drive about 2.8 miles to the end of the road where you can park at Guffey Bridge.

0.0  0.0  **STOP 2.1: Walters Butte quadrangle—the Bonneville Flood and volcanoes.**

**THE BONNEVILLE FLOOD**

**Bonneville Flood bar at old railroad bridge near Guffey Butte.** This location is the upstream apex of a large, 10-kilometer-long expansion bar formed where the Bonneville Flood exited the constricted reach between Swan Falls and Guffey Butte. This bar is one of the largest deposited by the Bonneville Flood. It is composed of boulders, cobbles, gravel, and sand deposited in northwest-dipping (downstream) foresets and is capped by an armored surface of rounded and imbricating boulders and cobbles. A large scour hole (Jensen Lake) and pendant bar formed on the surface of the bar where the flow encountered White Butte (Figure 18). The bar surface was also locally channelled by post-depositional flow.

The largest boulder measured on this bar has an intermediate diameter of 4.6 meters and an estimated mass of 140 tonnes. Clast size of sampled areas of boulders decrease from a maximum average intermediate diameter of about 4 meters near this stop to less than 30 centimeters near the ID 45 crossing of the Snake River about 7 kilometers downstream. The decrease in clast size corresponds to a decrease in calculated stream power from about 1,000 watts m⁻² to about 100 watts m⁻² over the intervening distance as the flow slowed upon leaving the constricted reach upstream. These types of measurements have helped define the ability of large flows to transport large clasts (O’Connor, 1993, p. 52-58).

Deposition of this bar probably forced the Snake River somewhat south of
Figure 18. Locations of flood features, topography, and boulder measurements at Walters bar within the Swan Falls reach. Walters bar is a large expansion bar formed where the flow exited the confined canyon downstream of Swan Falls and entered a wider, ponded reach downstream. The boulder measurement site of smaller clasts at the apex of Walters bar is apparently on an inset surface formed later in the flow, after deposition of the main body of Walters bar. Local flow directions are defined by channels incised into the bar surface. Some aspects of the geology are taken from Malde (1989a). Topographic base from the Walters Butte (ID) U.S. Geologic Survey 7.5' quadrangle. From O'Connor (1993).
its preflood course. This is similar to many other reaches along the
Bonneville Flood route where large, boulder-mantled bars were deposited.
In contrast to abundant local evidence of lateral migration of the Snake
River as a result of the flood, there is little evidence of vertical incision or
downcutting by the Bonneville Flood except in very local settings. At this
site, Bonneville Flood deposits are exposed at present river level indicating
no postflood downcutting and probably little downcutting during the flood.

VOLCANOES

Figure 19 shows a new interpretation of the geology in the Walters Butte
quadrangle (Bonnichsen and Godchaux, in press). Within the Walters Butte
quadrangle, three buttes provide examples of the three types of
phreatomagmatic volcanoes (erupted in water or through ground water)
recognized in this region of the western Snake River Plain (Godchaux and
others, 1992). This "hydrovolcanism" was associated with Lake Idaho or
abundant near-surface ground water that existed before the deep incision of
the plain.

Walters Butte is an emergent volcano, a remnant of a large tuff cone that
may have had a roughly north-south string of four eruptive centers
(Godchaux and others, 1992). It emerged from relatively shallow lake
water to build an edifice above the water line.

White Butte is a subaqueous volcano that sat in the path of the high energy
waters of the Bonneville Flood. White Butte is composed primarily of a
variety of tuffs which Godchaux and others (1992) believe resulted from a
short-lived eruption subaqueous eruption.

Guffey Butte is a subaerial maar/tuff ring that erupted through saturated
sediments of the Idaho Group. Studies of fish biostratigraphy at Guffey
Butte by Smith and others (1982) suggest these floodplain sediments
postdate Lake Idaho and represent the close of deposition of the Glenns
Ferry Formation. The volcanic complex at Guffey Butte includes sediment-
bearing tuff, basaltic spatter and dikes (Bonnichsen and Godchaux, in
press). The nearby mesa, informally called "Guffey Table," is capped by the
basalt of Guffey Table, which flowed onto a pre-incision surface at about
2,900 feet in elevation. Amini and others (1984) reported a K-Ar date of
1.065 ± 0.7 Ma for the basalt of Guffey Table.

Six Pleistocene basalt flows occur within the Walters Butte quadrangle.
Hat Butte and McElroy Butte, located a few miles north of the Walters
Butte quadrangle, were probably the eruptive centers for several flows that
Figure 19. Part of the geologic map of the Walters Ferry quadrangle by Bonnichsen and Godchaux (in press).
UNITs IN WALTERS BUTTE QUADRANGLE

Sedimentary Units
- Qsh: Alkali
- Qbf: Bonneville Flood deposits
- Qg: Younger and older gravel deposits
- TiU: Idaho Group, undifferentiated

Volcanic Units
- Og: Basalt of Initial Point
- Ohsu: Upper basalt of Halverson Lake
- Ohsn: Middle basalt of Halverson Lake
- Oks: Basalt of Kuna Butte-Powers Butte type
- Otwa: Walters Butte volcanic complex
- Otwh: White Butte volcanic complex
- Otfj: Jinx Lateral volcanic complex
- Ogi: Basalt of Guffey Table
- Otgo: Guffey Butte volcanic complex
- Tgrb: Basalt of Guffey Railroad Bridge
- Tgpb: Fragmented pillow basalt

Figure 19. Continued.
predate the escarpment of the Melba alcove, a large stream-cut surface that forms the bench within which Walters Butte is centered. These basalts may be about 0.9 Ma (Bonnichsen and Godchaux, in press; Othberg and others, 1995). The basalt flows of Halverson Lake, from an unknown volcano, were the earliest basalts to flow into the Melba alcove. The scabland just north of this stop formed on the surface of these basalts. The youngest basalt flows known to erupt in this area are those from Kuna Butte-Powers Butte, Initial Point, and Grouch drain (Bonnichsen and Godchaux, in press). The Initial Point flows form frozen lava cascades where they passed over the escarpment of the Melba alcove. $^{40}$Ar/$^{39}$Ar dates for Kuna Butte-Powers Butte (0.387 ± 0.031 Ma) and Initial Point (0.414 ± 0.037 Ma) indicate the eruptions were closely spaced in time. The Grouch drain eruption took place during the middle to late Pleistocene, because the basalt lava from the eruptive center flowed downslope onto a relative low terrace of the Snake River. The basalts mapped in the Walters Butte quadrangle range in age from about 1 Ma to 0.4 Ma. During this period the composition of the basalts changed from an earlier, lower potassium content to a later, higher potassium content (Othberg and others, 1995).

Leave the Guffey Bridge parking lot and retrace the route along the old railroad grade.

2.0  2.0  Note 1-2 meter size of boulders on the surface of the bar.

2.2  0.2  Basalt scabland formed during the Bonneville Flood.

2.8  0.6  Turn left on Hill Road.

3.8  1.0  To the left of the road is a fosse (scour hole) on the upstream side of White Butte.

4.3  0.5  The side of a bar formed in the lee of White Butte. Note the larger grain size (cobbles and small boulders) on the armored surface.

5.1  0.8  Turn left on Ferry Road.

5.7  0.6  Crest of pendant bar behind White Butte.

7.1  1.4  Turn left on ID 45. Note fine grain size and cross-beds in gravel exposure.

7.6  0.5  Bridge over the Snake River at Walters Ferry.
8.1  0.5 Intersection of ID 78 and ID 45. Turn right and take ID 78 north toward Marsing.

16.2  8.1 Givens Hot Springs parking lot. This is a good stop for lunch and rest rooms.

To the east across the Snake River a Pleistocene basalt rim rock caps the basin-fill sediment of the Pliocene Glenns Ferry Formation. Two landslides are visible in the otherwise smooth debris slope at the base of the high bluff. In this area the Glenns Ferry Formation is composed mostly of stream overbank silt locally interbedded with channel sand and gravel. Toward the west and southwest, the Owyhee Mountains rise above the western Snake River Plain. Rhyolite flows and granite outcrops have formed a rugged surface in the foothills of the Owyhee Mountains.

From Givens Hot Springs continue driving north toward Marsing on ID 78.

27.8  11.6 Intersection of ID 55 and ID 78 at Marsing. Turn left toward Homedale.

29.8  2.0 Intersection of US 95 and ID 78. Continue toward Homedale on US 95.

This flat, low surface is a broad terrace buried by thin-bedded, fine-grained, slack-water sediments of the Bonneville Flood that are locally exposed in drainage ditches. The terrace is probably correlative with the Whitney terrace of the Boise Valley.

37.9  8.1 Homedale and intersection of US 95 and ID 19. Turn right and follow US 95 toward Wilder.

41.7  3.8 Gravels of the Deer Flat terrace are exposed in a road cut on the left just before reaching the surface the terrace.

42.4  0.7 Approximate contact with Bonneville Flood slack-water sediment, elevation about 747 meters (2,450 feet). The Deer Flat terrace escaped flooding.

42.7  0.3 Town of Wilder.

44.7  2.0 Turn right on Howe Road.

45.7  1.0 Turn left on Travis Road.

43
Turn left on Jacks Road and drive to the entrance of a silage pit about 400 feet from the intersection with US 95.

47.1 0.9  **STOP 2.2: Wilder terrace—silage pit.** This exposure shows the Wilder terrace is composed of the gravel capped by loess and Bonneville Flood slack-water sediment. The gravel clasts include volcanic lithologies carried into the Snake River from the Owyhee Mountains. A buried duripan formed in the top of the gravel is preserved. Correlation of the Wilder terrace with any of the eastern Boise Valley terraces is unclear, but it may be equivalent to either the Sunrise or the Gowen terrace. The duripan exposed at this stop has moderate morphological development similar to that of duripans associated with the Sunrise and Gowen terraces. Although not extensively sampled, chemical analyses indicate the duripan contains 64% CaCO₃, which is slightly more than any of the duripans sampled near Boise. The opaline SiO₂ content is similar to that of the Whitney terrace duripan.

The duripan is buried by a massive silt deposit, probably loess rapidly deposited by winds blowing silt from the late Pleistocene Snake River floodplain, that shows virtually no effects of pedogenesis. The loess is buried by thin-bedded, tan silt interpreted to be 14.5 ka Bonneville Flood slack-water sediment. Stringers of calcium carbonate extend vertically along fractures and horizontally along bedding planes in the slack-water sediment. This exposure lies along an escarpment between a nearly flat terrace surface and the gulch. As a result, the Bonneville Flood sediment is thinner here than away from the gulch where well logs show the thickness to be 10-14 feet. The freshness and lack of pedogenic effects in the loess underlying the Bonneville Flood sediment suggest that the loess was actively accumulating just before the flood. The loess, therefore, probably was deposited during the latest stages of the last Pinedale glaciation.

At less eroded sites, the Greenleaf soil (fine-silty, mixed, mesic Xeric Calciargid) has formed in the Bonneville Flood slack-water sediment and perhaps a thin mantle of loess. CaCO₃ has been leached to a depth of about 40 cm. A weakly developed argillic horizon is present immediately above this zone of CaCO₃ accumulation. The laminated fabric of the slack-water sediment is still visible in the lower part of the Greenleaf profile.

Leave the silage pit and turn right on US 95. Drive north to the intersection of US 20/26 and US 95.
47.7 0.6 Descend from the Wilder terrace through Mammen Gulch. Exposures of the gravel of Wilder terrace overlying the Glenns Ferry Formation are visible on the right.

48.5 0.8 Mammen Gulch opens onto the Whitney terrace, here buried by Bonneville Flood slack-water sediment.

Descend from the Whitney terrace onto the Boise River floodplain.

51.1 2.6 Intersection of US 20/26 and US 95. Park in the triangular median and on the shoulder. Cross the west- and north-bound lanes to view the road cut. Some of the vegetation in the drainage ditch may have to be removed to see the lower part of the section.

53.7 2.6 **STOP 2.3: Bonneville Flood slack-water sediment—current ripples.**
The upper part of this exposure shows thin-bedded silts similar to those mantling the Wilder terrace at Stop 2.2. Near the base of the exposure, however, the deposits are coarser. Ripple-drift laminated sand grades upward to thin-bedded silt with fine sand partings. The ripple-drift directions indicate an easterly current direction, opposite that of the present Boise River, providing evidence that the rising waters of the Bonneville Flood caused a reversal of stream flow in this part of the Boise Valley.

ENCORE STOP

Drive north on US 95 through Parma and past the turn to Nyssa. When the interchange with I-84 comes into view ahead, prepare to turn left on SW 1st Ave. The market, Farmer John’s Produce, is located at the southwest corner of the intersection of US 95 and SW 1st Ave., but sits back from the highway. Drive west on SW 1st Ave. past Farmer John’s Produce. At about one-half mile the road descends a grade to the intersection with Whitley Drive. Old gravel excavations and road cuts on the right expose a sandy gravel overlain by a series of loess deposits and buried soils. Park on the narrow shoulder.

**Palisades Corner** (Palisades Corner is one-half mile east next to the I-84 interchange).

Very little research has been done at this locality, but the exposure provides more loess stratigraphy than can be seen elsewhere in this part of the western Snake River Plain. At least seven buried soils have been tentatively identified here. From the top of the section, up to 4 meters of massive sandy silt (very fine, sandy loam) overlie the thin-bedded Bonneville Flood slack-water deposits, indicating a significant accumulation of wind-blown sediment in the past 14,500 years. As at the Wilder silage pit (Stop 2.2), the slack-
water deposits are underlain by a massive silt, interpreted to be loess, which is about 3 meters thick here. The base of this silt appears to grade into a buried soil. Below this level is about 10 meters of several loess deposits separated by buried soils. These have varying degrees of argillic, calcic, and duripan development. At the lower end of the road cut pebbly sand is exposed which increases in gravel content with depth. The approximate elevation of this deposit suggests a correlation with the Wilder terrace (Stop 2.2).

Return to US 95 by continuing north underneath I-84, and then turn right at the next intersection on NW 1st Ave. Drive one-half mile east on NW 1st Ave to US 95. From here the I-84 interchange is about three-quarters of a mile south.

REFERENCES

Currey, D.R., 1990, Quaternary palaeolakes in the evolution of semidesert basins, with special emphasis on Lake Bonneville and the Great Basin, U.S.A.: Palaeogeography,

Currey, D.R., G. Atwood, and D.R. Mabey, 1983a, Major levels of Great Salt Lake and Lake Bonneville: Salt Lake City, Utah, Utah Geological and Mineral Survey Map 73.

Currey, D. R., and C.G. Oviatt, 1985, Durations, average rates, and probable causes of Lake Bonneville expansions, stillstands, and contractions during the last deep-lake cycle, 32,000 to 10,000 years ago: Geography Journal of Korea, v. 10, p. 1085-1099.


Lindgren, W., 1898, Description of the Boise Quadrangle, Idaho: U.S. Geological Survey
Geologic Atlas, Folio 103. 7 p.
———, 1988, Changeover from basin-filling to incision in the western Snake River Plain: Geological Society of America Abstracts with Programs, V. 20, no. 6, p. 461.


