Geologic Map of the Grand View-Bruneau Area, Owyhee County, Idaho

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Technical Report 98-1
December 1998

Contents

Figure

Plates

The following 7.5-minute quadrangles in this report are purchased separately:

Pence Butte, Pot Hole Butte, Bruneau Dunes, Hot Spring, Crowbar Gulch, Austin Butte, Bruneau, Sugar Valley, Broken Wagon Flat, Table Butte, C.J. Strike Dam, Little Valley, Hole In Rock, Grand View, Chalk Hills, Big Horse Basin Gap, Vinson Wash, Perjue Canyon, and O X Lake

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INTRODUCTION

A grant from the Idaho Department of Water Resources funded the mapping of nineteen 1:24,000-scale quadrangles. The grant was part of a much larger research project funded by the U.S. Fish and Wildlife Service. Our part provided detailed geologic information on surface lithologic and structural elements. This information was used by scientists with the Idaho Department of Water Resources and the U.S. Geological Survey's Water Resources Division in their hydrogeologic study of the Bruneau-Grand View area geothermal aquifer.

Our field work on the project began in the spring 1990 and ended in the fall 1991. The field work was supplemented with observations from 1:31,680-scale color stereo air photographs. In addition, Bonnichsen performed chemical analyses on samples of the basaltic and rhyolitic units at the laboratory facilities of the University of Massachusetts, Amherst, Massachusetts. Bonnichsen and Godchaux drilled cores in the rhyolitic units for analysis at the paleomagnetic laboratory facilities of Eastern Washington University, Cheney, Washington. Our understanding of lacustrine sedimentation was enhanced by Jenks' attendance at two professional meetings: the Geological Society of America's Penrose Conference on Large Lakes and the Friends of the Pleistocene field trip to the Lake Bonneville basin.

In our maps we use many new concepts about the geologic history of the western Snake River Plain. Since the 1920s, scientists have believed that the western Snake River Plain in the late Tertiary was a large river valley, sometimes occupied by ephemeral lakes. Based on our mapping and previous work, we have returned instead to the nineteenth century idea that the western Snake River was occupied in the Miocene to Pleisto-

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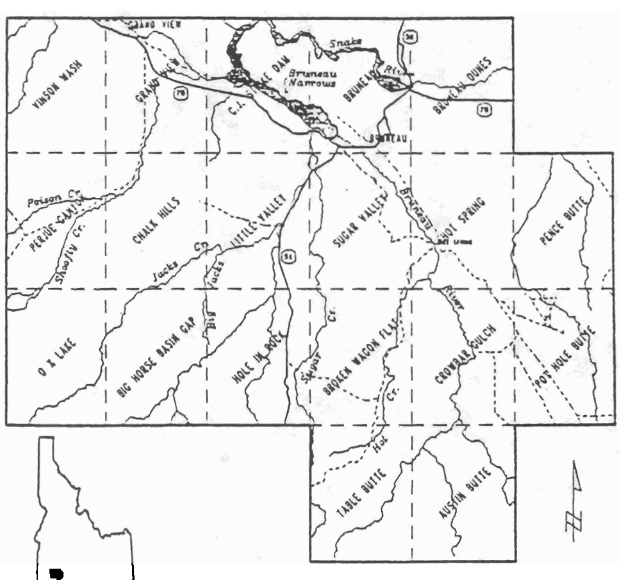
cene by a large lake, Lake Idaho. This concept of a stable, long-lived lake is an important change in how scientists view the sedimentary and volcanic history of the plain. By mapping marker beds and defining most of the complex volcanic stratigraphy, we have laid the foundations for detailed sedimentological and stratigraphic work. In addition, our new structural information will contribute to an understanding of the basin's complex tectonic history.

LOCATION

The study area is composed of nineteen 7.5-minute quadrangles (Figure 1): Pence Butte, Pot Hole Butte, Bruneau Dunes, Hot Spring, Crowbar Gulch, Austin Butte, Bruneau, Sugar Valley, Broken Wagon Flat, Table Butte, C.J. Strike Dam, Little Valley, Hole In Rock, Grand View, Chalk Hills, Big Horse Basin Gap, Vinson Wash, Perjue Canyon, and O X Lake. These quadrangles occupy longitudes 115° to 116°15′ and latitudes 42°30′ to 43°. The study area lies primarily south of the Snake River within Owyhee County and includes the towns of Bruneau and Grand View. Elevations range from 6,062 feet (1848 m) in the O X Lake quadrangle to 2,360 feet (719 m) along the Snake River in the Grand View quadrangle. Major topographic features include the Bruneau, Little, and Sugar valleys and the Bruneau River, Little Jacks Creek, Big Jacks Creek, and Snake River canyons. Bruneau Dunes State Park is on the east side of the area, occupying Eagle Cove within the Snake River canyon.



Scale 1:360000

Figure 1. *Location map of the study area.*

The land is mainly used for cattle raising and farming. Most of the farming is in the valleys and low areas south of the Snake River. The southern Idaho region is arid, so crops are irrigated from wells or from the stream flows of the Bruneau and Snake rivers. Major crops include hay, sugar beets, grain, beans, mint, and potatoes. The lower country is also used for wintering cattle, which are moved to pastures in the higher elevations for the summer. The Simplot Corporation operates a large cattle feedlot just north of Grand View.

The region usually receives less than 10 inches (25.4 cm) of rain a year at the lower elevations. Temperatures vary from -30°F in winter to 110°F in summer. The sparse population is concentrated in the agricultural areas at the lower elevations. Much of the country is uninhabited. The unpopulated areas are mainly federal land managed by the U.S. Bureau of Land Management. Military aircraft from nearby Mountain Home Air Force Base also use the area around Pence Butte in the Pence Butte quadrangle as a bombing range target.

The natural vegetation, the Great Basin high desert flora and fauna, varies depending on elevation and precipitation. Russian olive, willow, and cottonwood trees grow at the lower elevations along the rivers. At the middle elevations, sagebrush is the predominant plant, with lesser amounts of rabbit brush and salt brush. In years of normal spring rainfall, wildflowers are plentiful and varied. At high elevations sagebrush is still the dominant shrub, but juniper trees are also abundant.

The best access to the field area (Figure 1) is through Mountain Home either on Idaho Highway 51 to Bruneau or on Idaho Highway 67 to Grand View. Idaho Highway 78 connects these two towns. Highway 51 continues south to the Nevada border from a crossroads just west of Bruneau. The other two principal paved roads are the Hot Spring Road on the east side of Bruneau Valley and the Mud Flat Road just east of Grand View. Graveled roads are numerous, and access to the entire area is generally good.

GENERAL GEOLOGIC SETTING

Regionally, the area is at the intersection of the western Snake River Plain graben and the NE-SW trend of volcanism that caused the formation of the eastern Snake River Plain. The western Snake River Plain is a classic rift graben, in some ways similar to the rift basins of East Africa. It formed tectonically, and large normal faults define its northeast and southwest sides. Bimodal volcanism dominates the stratigraphy in both the eastern and western plains. Volcanism began with rhyolitic ash and lava flows and culminated with the eruption of basaltic volcanoes.

The oldest rocks in the mapped area are on the west side. They are rhyodacite ash-flow tuffs correlative with the Challis Volcanics (40 Ma) of south-central Idaho (Ekren and others, 1981). This correlation is based on the lithologic characteristics of the rocks and on a single K-Ar date.

The southern part of the area falls within the northern boundary of the Bruneau-Jarbidge eruptive center (Bonnichsen, 1982). The eruption of large amounts of ash-flow tuffs, the Cougar Point Tuff units, created this structural depression at approximately 11.3 Ma (K-Ar whole rock; Bonnichsen and Citron, 1982). Beginning about 10 Ma (K-Ar whole rock), rhyolite lava flows and basalt shield volcanoes filled and covered the depression of the eruptive center.

Bimodal volcanism continued with the eruption of the rhyolite lava flows (Kauffman and Bonnichsen, 1990; Bonnichsen and Kauffman, 1987). The flows were erupted in the south and southwest parts of the area. The largest, the rhyolite of Sheep Creek, has a total extent of approximately 400 square miles (1,000 km^2). These lava flows probably erupted from north- to northwest-trending fissures. However, only one area, in the rhyolite of Horse Basin, has been identified as a vent.

Following the rhyolite lava flows, the volcanism changed to the eruption of basaltic shield and hydroclastic volcanoes. Many of the units show interactions with water, probably the waters of Lake Idaho. Only one of the almost fifty basalt units we have identified has been dated (whole rock K-Ar). The 8.4 ± 0.7 Ma and 8.8 ± 0.5 Ma dates (Armstrong and others, 1975; 1980) are from a single sample collected by W. P. Leeman from the bottom of the Hot Creek drainage near the Indian Bathtub Hot Springs (Armstrong and others, 1975). The sample is from either the basalt of Hot Creek or the basalt of Indian Bathtub. These dates may, however, be incorrect by some factor, because near the sample location both units contain large areas of water-affected basalt (see the introduction to the volcanic units for a description of water-affected basalt). The exchange of ions that occurs in the process of making water-affected basalt probably skews the amounts of potassium and argon now present in the basalt. Further research that dates more of the volcanic units will resolve whether or not the present dating is accurate.

With our mapping, we are developing a better understanding of the ancient Lake Idaho system. Although an exact beginning date for the lake system is still unavailable, the lake probably began sometime in the late Miocene after the eruption of all rhyolitic units. With numerous major and minor fluctuations, the lake probably continued in some form into the Pleistocene. During most of this time the lake occupied a large slowly subsiding and deepening basin. Based on the present-day location of near-shore sediments, Lake Idaho — at its highest stand—was approximately the size of the present-day Lake Ontario. It covered the area from Twin Falls on the east to beyond the Oregon-Idaho border on the west.

A thick section of sediments intercalated with volcanic units accumulated within the Lake Idaho basin. For the most part, shorelines in the lake basin had relatively low gradients. Thus, the major thicknesses of sediments deposited in the basin during most of its history are all in the small pebble- to clay-sized fractions. During its final recession, alluvial processes eroded large amounts of these fine-grained sediments. Additional sediments eroded as faulting continued to form the western Snake River Plain during and after the final recession of the lake. In some areas we see only fragments of sedimentary sections, where they were protected from erosion by the formation of small downfaulted grabens. Throughout the basin, the vast quantities of sediments removed by erosion are more impressive than the major thicknesses of sediments that remain.

As in most modern large lake systems, deposits in the Lake Idaho system were chiefly influenced by the amounts and types of sediments eroded by tributary drainages. Within the area the most dominant and long-lived tributary drainage apparently was the ancestral Bruneau River. The river constructed a complex network of deltas where it deposited sediment at the edge of Lake Idaho. We have found gravels composed entirely of Bruneau River drainage lithologies as far west as the Vinson Wash quadrangle. Therefore, during low stands of the lake, the Bruneau River probably was the major through-going drainage. Our emphasis on tributary sources as the cause for lateral differences in the sediment packages around the lake basin contrasts with the hypothesis of Malde and Powers (1963). They and other earlier researchers believed the sediments were deposited by a single through-going drainage, possibly even the present Snake River.

Most large lakes with the longevity of Lake Idaho (like present-day Lake Turkana in Africa and Lake Baikal in Asia) undergo many fluctuations in water level. While occupying the basin, Lake Idaho probably never dried up completely. However, it did experience at least more than one major recessionary event. These were probably caused by both tectonic and climatic changes to the basin. Tectonic events may have altered the configuration of the outlet and therefore the base level of the lake. Increased or decreased amounts of precipitation undoubtedly caused other water-level fluctuations.

Although some fluctuations were linked to seasonal cycles, others occurred at intervals of 100,000 or 1,000,000 years and possibly were the result of major climatic changes. These fluctuations reworked and redeposited the sediments in the near-shore environment. Thus, the near-shore environment is the most complex and difficult for geologists to reconstruct. However, the environment is also the most interesting for geologists because it contains a variety of sedimentary facies. The near-shore environments include reefs, gravel and sand beaches, and oolite sandbars. The lacustrine reefs, like marine barrier reefs, formed parallel to the shoreline and contained a variety of organisms. In the sand to gravel beaches are found major deposits of fish bones, mollusc tests, and petrified wood. Some areas appear to have been relatively starved of clastic sediment, allowing the formation of major thicknesses of prograding oolite sandbars. The most widespread shoreline lithology — sand — is also the least consolidated and resistant to weathering. Thus, sand is the most difficult lithology to map. However, we can infer the locations and sizes of the sand layers from the presence of large Holocene dune sand fields in parts of the area.

Previously, we and other researchers thought the deeper environments would contain only very fine-grained sediment packages. However, large lakes mimic oceans by producing currents and waves. These form sedimentary structures that look similar to those made by the same processes in oceans and streams. Thus, earlier researchers have mistakenly assigned some lacustrine deposits to fluvial origins. Major storms can create currents in lakes that reach depths of 330 feet (100 m). When large waves caused by these storms beat against the lake shorelines, they move the coarser-fraction sediment particles into the central and deeper parts of the lake. Near the river and larger stream deltas, both storm-generated currents and annual spring runoff floods may cause the formation of turbidity currents. The turbidity currents are another way in which the coarser near-shore sediments are moved into the centers of the lake basins.

We are just beginning to fully understand these lacustrine sediments. We believe that the sediments remaining from Lake Idaho arguably offer a unique opportunity to study these complex facies relations in juxtaposition with actual datable strata. The presence within the lake sediments of numerous datable silicic ashes, as well as basaltic flows and tuffs, creates a framework that can be used to divide the sediments into facies packages. The datable volcanic units will allow sedimentologists to chronologically correlate sediment packages of diverse lithologies.

Paleontologists in the nineteenth century (Cope, 1883a, 1883b; Meek, 1870; Newberry, 1869) first recognized the existence of the lake from their examinations of lacustrine fossils. In recent years Smith (1975) and Smith and others (1982) have worked extensively with the abundant fish fauna and found a diverse population that included meter-long minnows and salmon. The fish fed on an abundant population of microfossils, including many species of both diatoms and ostracods. The shells of these microfossils are well-preserved in the fine-grained sediments.

A diverse mammal and vertebrate fauna that included swans, saber-toothed tigers, frogs, and camels (Jonena Hearst, oral and written comm.) also flourished on the shores of the lake. The famous Hagerman horse locality probably is related in some way to the lake, either as a shoreline feature or as sediments from a tributary stream, possibly the ancestral Salmon Falls Creek. Today, paleontologists are pursuing research in several areas, including work with pollen that will document variations through time in continental climates.

Lake Idaho probably drained slowly as the ancestral Snake River cut through Hells Canyon and breached the lake basin (Wheeler and Cook, 1954). Evidence for this final recession can be found in the fluvial gravel surfaces. The tributary streams first eroded the underlying sediments and then covered them with gravel. The lake possibly receded from the mapped area about 1.5 to 1.0 Ma. Evidence for this hypothesis comes from K-Ar dates (whole rock) of basalt units that are located outside the present mapped area. The change from lacustrine to subaerial conditions is documented in these basalt units. With the final recession, the present drainages formed within the basin, and the Snake River was at last established as the dominant through-going drainage. Tributary drainages, like the Bruneau River, also began to cut their canyons at this time.

Since the demise of Lake Idaho, several large structural valleys have formed within the area. The largest is the Bruneau Valley, which runs northwest-southeast through the eastern part of the area. Several alluvial fans have formed on both sides of the valley along the marginal fault scarps. The presence of the fans and their youthful appearance suggest that some of the movement on the valley faults may have been quite recent. We have noticed that the Bruneau River has only cut into the fans on the southwest side of the valley. Perhaps fault movement has caused the river to move in that direction.

The present Snake River canyon, located in the northern part of the area, may have been largely the result of the most recent major geologic event, the Bonneville Flood. Several pulses of floods, flowing as much as 1 million cubic feet a second, poured down the Snake River drainage after ancient Lake Bonneville breached the Red Rock Pass divide, south of Pocatello. The dating of shoreline features within the Lake Bonneville basin, which surrounds the present Great Salt Lake in northern Utah, suggests the flood occurred about 14,500 years ago (Oviatt, 1991). The incredible deluge of water down the Snake River canyon cut canyons, stripped sediments from basalt surfaces, and deposited large sand, gravel, and boulder bars in the bottom of the canyon. Evidence within the area suggests the flood reached as high as 2,900 feet in elevation. As evidence for this elevation, we have mapped both large landslides and stripped basalt surfaces near and within the present Snake River canyon. The flood waters saturated and undercut the sediments below the basalt canyon rims, causing them to fail.

STRUCTURE

Two sets of fault directions dominate the structural grain of the area. In the sediments most of the fault planes are covered with slope wash and talus and thus are very difficult to locate. However, reliable local indicators of faulting within the sediments include the following: (1) the offset of marker beds known to occupy only a certain stratigraphic position, (2) the presence of tilted bedding (more than 10°), and (3) the locations of cemented or more resistant areas of sediment. The offsets in the basalt and rhyolite units are easier to document, because in many places they are juxtaposed against sedimentary lithologies.

In the southern part of the area is a zone up to several miles wide, containing numerous horst and graben blocks. Some faults have offsets of as much as 250 feet (76 m), so that the sum of all displacements is in the thousands of feet. In addition to this zone, even larger boundary fault-sets drop down all rhyolitic units to form the present topographic southern edge of the western Snake River Plain basin. One of these major boundary faults, located in the Big Horse Basin Gap and the Perjue Canyon quadrangles, appears to have moved more recently than other similar faults. It has a youthful escarpment that has been cut by local streams to form small alluvial fans of sediment on the downthrown block.

In the relatively unconsolidated sediments that underlie most of the area, we were unable to locate actual fault planes or other indicators of fault motion. Based on the few faults traceable through offsets in marker beds, much of the faulting appears to be normal in motion. This is consistent with the idea that the western Snake River Plain is a rift-graben. In the area most of the fault movement appears to have occurred after the Lake Idaho sediments were deposited. In several locations fine-grained sediments butt up against escarpments of rhyolite as much as 400 feet (122 m) high. Even immediately adjacent to the large boundary faults, such as the faults in Broken Wagon Flat quadrangle that step down the rhyolite of Sheep Creek to the north, sediments beneath the capping gravels are not larger than small pebbles. The present juxtaposition of fine-grained sediments against rhyolite or basalt escarpments is further evidence for the presence of a relatively low gradient Lake Idaho shoreline during most of the lake's history.

The most obvious structural grain in the area strikes northwest-southeast. The grain is approximately parallel to the overall trend of the western Snake River Plain graben. The northwest-trending faults appear to be the youngest in the area. In some locations they offset all sedimentary and volcanic units, including the highest elevation, basin-fill gravels and the uppermost basalt flows. Examples of this trend are the large marginal faults that form the major rhyolite escarpments and the major faults that bound the Bruneau Valley graben. Another major set of northwest-trending faults is either continuously or sporadically exposed from the Bruneau River canyon, on the southeast, to the northwest corner of the Vinson Wash quadrangle.

The north- to northeast-trending faults, the second set of faults within the area, are less obvious in their topographic expression. However, they may actually be more important because they determine the stream patterns over much of the area. Evidence for these faults can be found in the offset of major marker beds and in the locations of fairly long and nearly straight canyon segments of major streams. A good example of the fault sets is the boundary faults on the northwest and southeast sides of the Little Valley graben. At the intersections of the two major fault sets, the northeast-trending faults affect and perhaps offset the northwest-trending structures. This effect suggests that the northeast-trending structures are older and probably have been active for a longer time.

As suggested earlier, the juxtaposition in many places of fine-grained sediments next to thick sequences of rhyolite is evidence that much of the faulting probably occurred after the final recession of Lake Idaho. The gravel surfaces deposited during and after the lake's recession obviously did not all form simultaneously in different parts of the basin. However, many of them still must be relatively young, ranging from 1.5 to 0.5 Ma, because they represent the change in the basin from being occupied by a stable large lake to an environment containing both rivers and lakes. In addition, base-level changes from post-lake faulting may have in part been responsible for the rapid downcutting of some streams, like the Bruneau River. Therefore, the Bruneau River canyon and its tributaries must also be fairly young. A probable age for this and other canyons might be 1 million years or less.

HOT SPRINGS

The Indian Bathtub Hot Springs, the focus of this study, is in the floor of the Hot Creek drainage. It is approximately 0.5 mile (0.8 km) southwest of the confluence of Hot Creek and the Bruneau River. Local ranchers report that in the past the hot spring issued from the Hot Creek streambed, upstream of a small waterfall. The springs presently issue below the waterfall from the red sediment bed between the basalt of Indian Bathtub and the underlying basalt of Buckaroo Dam.

While it is impossible to date the actual origin of the hot springs, it is possible to speculate on their probable control and origin. At the springs the units are not offset by faults. Elsewhere, particularly in the upper end of the Bruneau Valley, other hot springs do appear to be directly related to the fault sets that formed the Bruneau Valley graben. In addition, both upstream and downstream of the Indian Bathtub Hot Springs, faults do offset the units of the basalt and sediment package. It is possible, but difficult to prove, that the older northeast-trending structures control the location of the Hot Creek drainage at its confluence with the Bruneau River.

If the springs are not fault-controlled, then they could be the result of stream erosion having reached the level of a confined part of the aquifer. Thus, the springs would only have begun to flow as the erosion of the Hot Creek drainage reached its present depth. As we suggested in the section on structure, the drainage probably did not begin eroding until at least 1 Ma. If erosion is the controlling factor for the presence and location of the Indian Bathtub Hot Springs, then the springs have probably been in existence less than 1 million years.

Another control on the location of the spring may be partially related to the lithologies through which it issues. In other nearby locations, features in the basalt and sediment stratigraphy suggest that a local lowering of the level of Lake Idaho occurred between the emplacements of the basalt of Buckaroo Dam and the basalt of Indian Bathtub. The basalt of Buckaroo Dam is completely water affected throughout its exposure, suggesting that it flowed beneath the waters of Lake Idaho. The overlying sequence of sediments grades from a lower silty clay to an upper clean sand. This change in facies is consistent with a recession of the lake shoreline. The bottom two flows of the basalt of Indian Bathtub appear to have been subaerially emplaced, but the flows above them are extremely water affected. Most water-affected basalt flows are massive with few vesicles and with interstitial spaces filled with clay. The overlying and underlying water-affected basalts may confine the aquifer within the more porous sediments and scoriaceous subaerial basalt flows.

Another way to consider the age and future longevity of the Indian Bathtub Hot Springs is to look at hot springs as general geological phenomena. Geologically, hot springs are fairly ephemeral features in any landscape. Lowell (1992, p. 552-553) says:

> *Hydrothermal systems are fundamentally transient phenomena. The temporal variability may have a range of time scales. Heat input may vary as magma chambers solidify and cool, or are periodically replenished. . . . Permeability may change as a result of tectonic, thermal, or chemical effects. Fluid recharge patterns may change because of climatic changes (precipitation patterns, glacial episodes, etc.).*

Large continental hydrothermal areas such as Yellowstone Park may last for several tens of thousands of years, although individual subsystems may have a shorter lifetime.

Two geologic factors that can possibly affect the life spans of springs in this area are (1) the amount of dissolved solids carried by the spring water and (2) the presence of local or regional earthquake activity. All hot springs tend to plug the faults and pore spaces that are their plumbing systems. Where they issue from the ground, they meet a zone of lower pressure and temperature. Thus, the dissolved solids carried in the hot, pressurized water are likely to be precipitated at, as well as below, the spring/surface interface. The precipitation tends to plug the subsurface fractures and sedimentary spaces through which the water travels. Precipitation of dissolved fluids is one of the primary reasons why hot springs do not exist for geologically lengthy periods. Although we have not observed precipitated deposits at Indian Bathtub Hot Springs, the high percentage of dissolved solids in this and other springs in the area (Charles Berenbrock, oral comm.), as well as the presence of older cemented areas in the sediments, suggests that subsurface precipitated deposits may exist in the Indian Bathtub Hot Springs.

The Indian Bathtub Hot Springs is within the Snake River Plain, adjacent to seismically active areas. Major earthquakes occurred in 1959 in the Yellowstone National Park area and in 1983 near Borah Peak in central Idaho. These earthquakes caused changes in both cold and hot springs in the immediately affected region (Roy Breckenridge, oral comm.). Following the earthquakes, some springs flowed more and others less. Piper (1924) reports that the 1906 San Francisco earthquake was felt in the Bruneau basin and affected both the locations and the flows of the area's hot springs. Earthquake activity anywhere within or adjacent to the western Snake River Plain basin will have some effect on the hot artesian wells and springs in the Indian Bathtub Hot Springs area. However, we cannot predict the actual manifestation of that effect on any particular spring.

With all these factors in mind — the typically short lives of hot springs, the springs' tendency to become plugged by the minerals dissolved in the water, and their vulnerability to seismic events — we believe it is important to view the Indian Bathtub Hot Springs geologically as well as historically. Geologically, the springs, and by extension the plants and animals that inhabit them, are a transitory rather than a permanent feature of the landscape.

ACKNOWLEDGMENTS

The authors are happy to thank the Idaho Department of Water Resources for funding the grant that made possible the mapping of this important part of the Snake River Plain. We also want to thank Kurt Othberg, Loudon Stanford, Paul Castelin, Janet Crockett, and Ken Neely for their helpful reviews. Charlotte Fullerton and Jennifer Churchill provided assistance in the preparation of the final report.

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DESCRIPTION OF UNITS

SEDIMENTARY UNITS

Approximately 80 percent of the mapped area is underlain by sedimentary beds. For convenience, we have grouped the sediments into three categories: the younger unconsolidated sediments, the gravel surfaces and lenses, and the Idaho Group sediments. Some units among the three groups overlap in age. We have noted these equivalencies within individual unit descriptions.

Younger Unconsolidated Sediments

The unconsolidated sediments are generally the youngest units in the area. They were formed either by recent stream and aeolian activity or by the Bonneville Flood. They are Holocene to Pleistocene in age. The alluvial fan deposits and alluvium are the result of recent stream activity. We have divided the dune sand into two units, vegetated and unvegetated. The locations of these pervasive and large sand deposits are, of course, due in part to prevailing wind directions. They also seem to be related to nearby large uncemented sand layers within the Idaho Group that are sources for the dune sand. Thus, the dunes may be used to some degree as indicators for locating the positions of the older sand deposits. The intermittent lake sediments are also the result of aeolian action. These clay-sized windblown sediments are accumulating in the shallow depressions in the underlying volcanic units. The landslide deposits and the Bonneville Flood deposits are both located exclusively within the present Snake River course. They were formed by the massive Bonneville Flood, caused by the rapid drainage of Pleistocene Lake Bonneville in northern Utah.

Qal Alluvium (Holocene) — Unconsolidated stream and valley deposits, including clay, silt, sand, and gravel. The unit is located throughout the area in the bottoms of the present stream and river drainages, where the deposits conform to the present topography.

Qil Intermittent lake sediments (Holocene) — Clay- to silt-sized sediments transported largely as windblown loess and deposited into lakes formed by depressions in the surfaces of the underlying basalt and rhyolite flows. When dry, the sediments form deep polygonal mud cracks, which in some lakes are outlined by small pebbles. Cobble- to boulder-sized rocks of the underlying volcanic lithologies also lie upon the surface of the fine-grained sediments.

Qfs Fresh, unvegetated dune sand (Holocene) — Large active dune fields that crop out only in the eastern part of the mapped area. The largest of these active dunes is in Bruneau Dunes State Park, which occupies Eagle Cove on the south side of the Snake River. With the tallest dune in the park measuring 470 feet (143 m), they are the tallest single-structure dunes in North America. Some active dune fields, located elsewhere within the study area, were too small scale to map.

Qaf Alluvial fan deposits (Holocene and Pleistocene) — Deposited on the downthrown sides of major faults. The greatest concentration of fans is along the walls of the Bruneau Valley. The drainages that created the fans have relatively small watersheds, some less than 1 mile (1.6 km) in length. Thus, the alluvial fan deposits are composed of a mixture of clast sizes, eroded from the local sediment deposits, that range in size from clay to gravel. Recent floods on the fans during our field seasons show that sheet wash during major thunderstorms is one of the principal mechanisms of fan growth.

Qds Vegetated dune sand (Holocene and Pleistocene) — Large and widespread fields of vegetated dune sand are a major feature of the area's landscape. Derived from nearby sand beds, each field is a unique shape and size, depending upon the underlying topography and the local prevailing winds.

Qls Landslide deposits (Holocene and Pleistocene) — Probably produced in part by the passage of the catastrophic Bonneville Flood as well as by long-term canyon slope processes. Most deposits are along the Snake River canyon. There, valley walls, cut in sediments capped by basalt rims, were saturated and undercut by the flood water. The saturation and erosion caused numerous massive slides. Some of the slide areas stretch for several miles along the uppermost as well as the lower canyon rims. In other areas debris falls, debris flows, and slump deposits are the result of the normal long-term mass wasting of the canyon walls. The only major slide area outside the Snake River canyon is within the Bruneau River canyon in Crowbar Gulch quadrangle. It was probably caused by movement on the fault that offsets the units exposed in the canyon walls near the slide zone.

Qbf Bonneville Flood deposits (Pleistocene) — Sand- to boulder-sized sediments that form sand, gravel, and boulder bar deposits. Most deposits are within the

Snake River canyon, but a few are also in the lower end of the Bruneau Valley near the Bruneau Narrows.

Gravel Surfaces and Lenses

Extensive gravel surfaces are one of the most prominent topographic features of the mapped area, as well as other areas of the western Snake River Plain. The gravels are intercalated within the finer grained sediments and also make surfaces overlying the sediments.

The local streams and rivers that drained into the Lake Idaho basin deposited the sediments they carried as deltas or alluvial fans. Therefore, these gravel deposits vary from area to area in the predominant clast lithologies. The variability is directly correlative with the lithologies of the source rocks underlying the basins drained by each ancient tributary stream or river system. We did not perform point counts for each gravel location; instead, we noted the quantities of the principal lithologies for any gravel surface we visited. For the surfaces visited, we have differentiated the gravels by their approximate predominant lithology or lithologies. The gravels of unvisited sites are lumped into an undifferentiated unit.

The gravel surfaces also lie at different elevations. Where the surfaces lie at elevations lower in the stratigraphic section, we were unable to determine the particular process, or perhaps the combination of processes, that formed them. Talus and slope wash from the overlying rocks and sediments have covered the back edges of the surfaces, obscuring the exact stratigraphic relations. Thus, any individual surface could be the result of one or more of the following processes: (1) downfaulting of a surface from a higher to a lower elevation; (2) exhumation of an intercalated gravel deposit by the erosion of the overlying finer grained sediments; or (3) terrace formation during the development of the present drainage valleys. These three processes directly affect how we view the relative ages of the surfaces. In process 1, the two surfaces are the same age; in process 2 the upper elevation surface is the youngest; and in process 3 the upper elevation surface is the oldest. To deal with this problem, we have chosen a mapping method that is strictly descriptive. We have not attempted to differentiate the relative ages of the gravel surfaces based on any single model or process. We suggest that the uppermost gravels, both in elevation and stratigraphy, and any intercalated gravels are Tertiary in age. These lenses and surfaces are the result of the gradual base level changes caused by the filling and draining of the Lake Idaho basin. The *QT* classification of the lower elevation gravels means that they could be either Quaternary or Tertiary in age and that their process of origin is unknown.

QTg Gravel surface, lithology undivided (Quaternary or Tertiary) — Located throughout the area, the surfaces are placed in this general unit but are probably correlative with the nearby surfaces whose lithologies we have verified and described. However, where we did not visit the localities, and their locations make designations questionable, we have lumped them into this undivided unit. Clast size ranges from pebble to boulder.

QTgq Gravel surface, abundant quartzite (Quaternary or Tertiary) — Principally located in the area surrounding the present Bruneau Valley. The unit is also to the north along and within the Snake River canyon as far west as Vinson Wash quadrangle. The gravel surface was deposited by the same drainage, the ancestral Bruneau River, that laid down the *Tgq* unit. It is similar in physical characteristics and constituent lithologies to the *Tgq* unit. Thus, in some locations where the unit is contiguous to an outcrop of *Tgq*, the surface is probably correlative with the adjacent *Tgq* outcrop and has been exhumed. In other locations it could be either downfaulted or reworked from the overlying *Tgq* unit.

QTgqb Gravel surface, abundant quartzite, significant basalt (Quaternary or Tertiary) — Located throughout the upper reaches of the Bruneau Valley and east of the West Fork of Browns Creek in the Pence Butte quadrangle. The unit contains the same lithologies as found in *Tgq* and *QTgq* but also has significant quantities of basalt clasts. In addition, in contrast to the quartzite clasts in the *Tgq* and *QTgq* units, the outsides of the clasts in this unit are unstained. Because it is the lowest elevation gravel surface in the lower Bruneau River drainage, the unit may have two possible origins. First, as stratigraphic position suggests, it may be the oldest of the gravel surfaces and simply has been exhumed by erosion. Second, it may be the most recent terrace formed by the Bruneau River within its present canyon. In this case, it would be the youngest of the gravel surfaces in the Bruneau River area.

QTgr Gravel surface, abundant rhyolite (Quaternary or Tertiary) — Covers surfaces in the central and southern parts of the area. The unit contains similar lithologies and in some locations is probably correlative with the contiguous or higher elevation exposures of the *Tgr* unit.

QTgrb Gravel surface, abundant rhyolite, significant basalt (Quaternary or Tertiary) — Located in the center of the area, the unit outcrops at two different elevations. At both elevations it contains significant quantities of basalt clasts. The first surface location is at lower elevations, just above the present creek bottom in the lower part of the Sugar Creek drainage in the Sugar Valley and Broken Wagon Flat quadrangles. These deposits differ somewhat from the more widespread *QTgr* deposits; the rhyolite clasts are large vitrophyre boulders instead of smaller devitrified clasts. The second *QTgrb* surface elevation is higher and crops out on both sides of Idaho Highway 51 in the Hole In Rock and Little Valley quadrangles. In these deposits the rhyolite clasts are smaller and composed of both vitrophyre and devitrified rock. Thus, the rhyolite clasts in these higher elevation surfaces are similar to the typical rhyolite clasts in the *QTgr* and *Tgr* units.

QTge Gravel surface, abundant Eocene volcanics (Quaternary or Tertiary) — Covers many of the surfaces in the west part of the area. The unit contains the same lithologies as the *Tge* unit. Thus, it may be correlative with any *Tge* lenses that outcrop within the fine-grained sediments near this unit. However, the unit probably is not correlative with the small *Tge* surface to the southeast of the *QTge* surfaces in Perjue Canyon quadrangle.

Tgq Gravel lens or surface, abundant quartzite (Tertiary) — Covering a large part of the eastern side of the area, the unit underlies both Horse Hill and the highest elevation surface east of the Bruneau River drainage. The deposits appear to be fluvial in origin and may be the remnants of a series of Bruneau River deltas. Clasts range in size from sand to large cobble. Common lithologies are Valmy Formation quartzite, Cougar Point Tuff, and Jarbidge rhyolite, all eroded from their exposures near the Nevada-Idaho border in the upper parts of the Bruneau River drainage. A prominent feature is the large, up to 2.0-feet (0.6 m) in diameter, quartzite cobbles whose outer surfaces are stained orange to gold to tan. The surfaces of some clasts are also covered with percussion marks, caused by the impacts between clasts as they were being transported in the river system. Basalt clasts are very rare in the gravel. This absence is interesting because at the time the gravel surfaces were deposited, the Bruneau River drainage flowed north from the Nevada border over more than 50 miles (80 km) of previously emplaced basalt.

Tgqb Gravel lens, abundant quartzite, significant basalt (Tertiary) — Located only in the Hot Spring and Pence Butte quadrangles. The unit contains the same lithologies as *Tgq*, but it also has significant amounts of basalt clasts. These gravel lenses, intercalated with the Idaho Group sediments, are at the same elevations and probably are correlative with the nearby *QTgqb* surfaces.

Tgr Gravel lens or surface, abundant rhyolite (Tertiary) — Covers much of the south part of the area, north of the marginal western Snake River Plain faults. The deposit is dominated by clasts eroded from the nearby rhyolite lava flows. The nearby source contrasts with the other gravel surfaces, also composed partially of rhyolite clasts but from more distant sources, like the Jarbidge and Silver City rhyolites. Probably the *Tgr* surfaces are the remnants of large alluvial fans or deltas. The fans built out from the escarpments made by the movement of large margin-basin faults. The fans formed along the edge of Lake Idaho during its final recession. The clasts range in size from pebble to cobble, and in some places appear to be more angular than comparable clasts in the *Tgq* unit. The deposits of the unit are probably correlative with any *QTgr* surfaces at similar elevations.

Tge Gravel lens or surface, abundant Eocene volcanics (Tertiary) — Located on the west edge of the area. The unit is intercalated with Idaho Group sediments and also covers a small area on the north side of Poison Creek. It contains several different lithologies, and its multicolored appearance is an identifying characteristic. Clasts include granite, quartz vein pieces, Eocene volcanics, rhyolite lava flow rocks, and obsidian. The clasts are sand- to cobble-sized and subangular. Where intercalated, the unit may be correlative with the adjacent and similar elevation *QTge* surfaces. However, the surfaces underlain by this unit near Poison Creek are probably not correlative, given their differences in elevation and distribution. Instead, these areas may be the result of deposition from an ancestral Poison Creek drainage.

Tgeb Gravel lens or surface, abundant Eocene volcanics, significant basalt (Tertiary) — Covers much of the upper surface on the west side of the area. The unit contains all lithologies found in the *Tge* and *QTge* units but additionally has significant quantities of basalt clasts. Grain size ranges from sand to cobble. Probably because of the high sand content and smaller grain size, the unit does not make horizontal and relatively undissected surfaces similar to those underlain by *Tgr* and *Tgq*. Instead, the *Tgeb* surfaces cap more deeply incised sand sections.

Idaho Group Sediments

The first geologists mapping in the area, Lindgren (1898), Lindgren and Drake, (1904), and Russell (1902, 1903a, 1903b), divided the sedimentary units into two formations, the Payette and the Idaho. These two formational divisions were based on relative stratigraphic position and on ages assigned by paleontologists to fossils collected from the area by earlier scientific explorations (Cope, 1883a, 1883b; Meek, 1870; Newberry, 1869). Buwalda (1921) and later Kirkham (1931) devoted their research efforts in the Weiser area to distinguishing the two formations in more detail and to suggesting depositional environments. Both Kirkham and Buwalda argued that most sediments in the western Snake River Plain are fluvial in origin and were deposited in a large river valley that at various times and in different areas contained pluvial lakes. Later, Malde and Powers (1962) adopted this hypothesis. They also raised the Idaho Formation to group status and divided it into several primarily fine-grained sedimentary formations containing basalt interbeds — the Bruneau, the Glenns Ferry, and the Chalk Hills as well as a number of gravel units. They appear to have distinguished these formations on the basis of a few scattered paleontological localities and by the relative elevation differences. We found, however, that because of the multilithologic character, the formations are not mappable. Either we were unable to trace them laterally, or we could not clearly distinguish them on the basis of lithology.

We began our work by mapping the individual volcanic units. Our intention was to trace each volcanic unit to its source. Unfortunately, this created problems with fitting our new volcanic stratigraphy into the previous, basically sedimentary framework. In some areas previous workers (Malde and others, 1963) had mapped the vent area of a volcanic unit as one formation and its related flows as another. Because only a single whole rock K-Ar date exists for all of the volcanic units in the area, we were thus unable to successfully assign our new volcanic units as members of the generalized sedimentary formations. In addition, evidence from the volcanic units (Jenks and Bonnichsen, 1987) strongly supported the existence of a large lake environment for the deposition of most sediments. The idea of a large lake, of course, was very different from the fluvial environment hypothesized by Malde and Powers (1962).

Given the unit assignment dilemmas posed by our new volcanic stratigraphy and our new large lake sedimentary model, we have abandoned the most recent formation names (Bruneau, Glenns Ferry, Chalk Hills, etc.) for the mapping in this report. Instead, we have returned to a simple designation and have mapped the fine-grained sediments as Idaho Group undifferentiated. In addition, to portray as much basic lithologic and stratigraphic information as possible, we have mapped several of the many marker beds intercalated with the Idaho Group fine-grained sediments. Each of these beds is individually distinct and traceable over mappable distances. The marker beds are generally near-shore facies that include fossiliferous cemented sands and gravels, oolites, and reefal limestones. We have also mapped layers of basaltic and silicic tephra as marker beds where they are significantly thick or numerous.

Ti Clay- to sand-sized sediments (Miocene to Pliocene) — The most widespread unit, covering much of the central part of the area. Intercalated within these fine-grained sediments are gravels, iron- and phosphatic-cemented sand and gravel layers, basalt flows, silicic and basaltic ashes, and limestone beds. Most exposures of the unit are poor, and where intercalated with or overlain by basalt flows, they are covered by basaltic talus. The percentage of sand beds to clay beds changes from basin edge to basin center (sand to clay). Percentages also change longitudinally along the lake's shoreline away from the deltas formed as tributary drainages intersected with the lake (gravel to sand to clay). The clay layers are thin bedded in some areas and more resistant than the sand layers. Some clay units contain fairly large amounts of gypsum as both strataform layers and cross-cutting veins. The cross-cutting relationships suggest that some of the gypsum may be from postsedimentation ground-water deposition. The sand layers are rarely exposed, are more abundant beneath the gravel surfaces, and are resistant only where they have been cemented by ground water. This cementation commonly follows the internal changes in porosity produced by the original depositional regime, creating abundant concretions that reflect the primary sedimentary structures (ripple marks, crossbeds, etc.). A few sand layers, deposited within thick clay sequences and closer to the center of the basin, were probably the result of turbidity currents from delta fronts and steeper shorelines. Therefore, they do not necessarily represent low stands of the lake.

Tsi Silicic tuff (Miocene to Pliocene) — The greatest thicknesses of silicic ash are interbedded with the fine-grained sediments in the west part of the area. Individual beds range in thickness from less than an inch to 15 feet (4.6 m). The ash colors vary from dark gray to white, and the individual ash layers vary from clean ash, with well-preserved glass shards, to reworked ashy silt. In many locations the ashes have been cemented with calcite and are therefore more resistant to erosion than the surrounding fine-grained sediments. We have not identified sources for these ash beds, but some of the thickest and most coarse grained of the clean ashes may possibly have nearby Snake River Plain sources. Other clean ash layers are very fine grained and thin, and they are probably the distal air-fall deposition from eruptions to the east in the Snake River Plain or to the west in the Cascade Mountains.

Tf Sand- to gravel-sized sediments, ferruginous and phosphatic cemented or stained (Miocene to Pliocene) — Located throughout the south part of the area. The unit probably represents near-shore beach sands and gravels. Clasts range in size from sand to cobble. The cementation and the red to brown to black staining both vary in amount. The cementation variations may be the result of postdepositional changes in lake water chemistry. Where the layers of the unit are strongly cemented, the bed forms a resistor within the finer grained sediments. Thus, over local areas, the unit is an important marker bed, and offsets of the unit by faults have helped us to understand the structure of parts of the area. Individual bed thickness generally ranges from 3 inches (7.6 cm) to 1.5 feet (0.5 m). The sediment layers contain fish and mollusc fossils and petrified wood, but the fossil abundance varies greatly from place to place. Although for this mapping we have lumped all occurrences of the cemented and stained beds together in a single lithologic unit, they probably are not all chronologically correlative. Instead, they may represent the locations of the beach/water interface at various times in the long history of the lake.

Tbs Basaltic tuff (Miocene to Pliocene) — Like the silicic tuff, the unit is located throughout the area but is most abundant in the lower Bruneau Valley near the Bruneau Narrows and around the upper end of the Bruneau Valley. The distributions of the tuff layers suggest that they may be from nearby hydroclastic volcanoes. Their coarse-grained outcrops near the Bruneau Narrows are adjacent to pillow deltas and may be reworked debris shed during the formation of the pillows rather than air-fall tephra from hydroclastic volcanoes.

Tls Limestone, undifferentiated (Miocene to Pliocene) — Several areas of limestone are not spatially connected with the reefal and oolitic limestone previously defined by other researchers (Straccia and others, 1990; Swirydczuk, 1980; Swirydczuk and others, 1979). Four of the areas are in the Sugar Creek drainage in the Broken Wagon Flat quadrangle. These outcrops are reefal or oolitic limestone and are adjacent to or near thick sections of water-affected basalt. A linear vein of massive to reefal-appearing limestone crops out on the common boundary of the Hot Spring and Sugar Valley quadrangles. This deposit possibly is the result of hot spring activity along a fault formed while the lake occupied the basin.

Thot Reefal limestone of Hot Spring (Miocene to Pliocene) — Located in the Broken Wagon Flat, Sugar Valley, Hot Spring, and Crowbar Gulch quadrangles in the southeast part of the area. The limestone, which was studied in detail by Straccia and others (1990), is a thick resistor within the fine-grained sediments of the area. The unit is thickest around the confluence of Hot Creek and the Bruneau River. It apparently has grown in ways similar to the coral barrier reefs and contains channels and armored colonies. The unit's overall shape suggests that it formed parallel to the ancient lake shoreline, with the channels at right angles to this trend. The channels, which are less resistant than the reef, commonly contain major deposits of mollusc shells. Straccia and others (1990) attributed an algal origin to this limestone. Our work suggests instead that the reef may have been formed by fresh-water sponges like those presently growing in Lake Baikal in Siberia (Farley Fleming, oral comm.). Parts of the unit contain as few as two and as many as eleven separate growth layers. These layers are truncated at their tops, suggesting that they were growing within the erosive reach of the waves. In some places, the bottommost layer sits on scattered pebbles. In other areas the bottom layer appears to rest directly on bioturbated silts.

Tsoo Oolite of Shoofly Creek (Miocene to Pliocene) — Located in the Vinson Wash and Perjue Canyon quadrangles on the west side of the area. Swirydczuk (1980) and Swirydczuk and others (1979) described the unit in detail. They suggested that the oolites formed as large prograding dunes or bars in a near-shore beach environment during a fairly long still-stand of lake levels. The ooids may have been aided in their growth by the presence of algae. In some areas the ooids are strongly cemented and iron stained. In others, where they are uncemented like the other uncemented sand deposits, they have been reworked by aeolian processes into vegetated sand dunes.

VOLCANIC UNITS

Basalt Volcanoes and Lava Flows

We have divided our discussion of the basalt flows in the area geographically into two sequences of units. One is in the north part and is exposed in the Snake River canyon. The other is in the south and southeast parts and exposed in and around the canyons of the Bruneau River, Little Jacks Creek, and Big Jacks Creek and their tributaries. No direct stratigraphic relationships exist between the two geographic sequences of units, making the production of an integrated stratigraphic column impossible at this point in our investigations. Also, in the south part of the area, sequences of basalt units exposed in some of the river and stream valleys are isolated from one another by the intervening and covering sections of sediments. Although Bonnichsen has chemically analyzed numerous samples of the basalt to help with correlations, the analyses were not ready for this report. Thus, we have not attempted to correlate the separate sequences of units. When the chemical data are complete, we will be able to correlate units in adjacent areas and drop one set of unit names.

The descriptions of the individual units are arranged in the following way. First, the flows in the north part of the area are discussed from youngest to oldest and then from east to west. Next, the units of the south part are arranged as spatially separate groups from east to west. Within each of the southern geographic groups, the units are discussed in their relative stratigraphic order, from youngest to oldest. For more precise stratigraphic relations, the reader should refer to the list of units in each quadrangle legend.

Flows in the units of the north sequence erupted from volcanoes near the town of Mountain Home. Flows in the units of the south sequence erupted from volcanoes to the southeast of their area of exposure. Flows in some units of each sequence ran for tens of miles away from their volcanoes.

Seven volcano vents are in the area. Five are shield volcanoes, and two are hydroclastic volcanoes. The vents of the hydroclastic volcanoes had some interaction with water or saturated sediments, probably related to the presence of Lake Idaho. The flows from the basaltic shields also interacted with the lake in one of two ways. Most flows interacted by forming what we have called water-affected basalt (WAB). When these flows ran into the lake, they did not interact in the familiar way to form pillow deltas or sequences. Instead, they appear to have flowed en masse without fragmenting along the bottom of the lake. In the process, they absorbed some quantity of water into their still-liquid lava. This water then interacted with the basaltic glass on a microcrystalline, interstitial level. The interaction caused the glass to be hydrated, either as the lava cooled or immediately after, to what we believe is a form of palagonite.

Upon erosion and exposure to the elements, the WAB flows appear to be extremely altered and weathered. In outcrop they form a slope of dark, gruslike crystal grains with what appears to be a powdery golden matrix. We believe that this apparent extreme weathering is caused not only by exposure to the weather but also by the further hydration of the palagonite, already formed in the rock, to clay. Since this change is on the interstitial level, the flows lose their usual resistant character and essentially fall apart from the inside out. All WAB units contain some areas that have been less affected by the palagonitization process. Thus, the WAB parts of the flows vary from small, 6- to 12-inch (15-30 cm) round areas to larger areas between joint surfaces and in the centers of columns, and finally to flows that are essentially all water affected, with only isolated areas of somewhat more competent rock. The more water-affected areas of the flows appear to be massive, with few vesicles, and without the diktytaxitic texture common to subaerial flows. Thus, these units may have more capacity to act as barriers to water flow than the vesicular to scoriaceous subaerially emplaced flows. Under some WAB areas, the heat from the flows has "baked" the underlying sediments to a bright red that is easily and continuously traceable over many miles of outcrop.

Where the flows appear to have cascaded over a beach face or escarpment, they form pillow deltas instead of WAB flows. We suggest that for the lavas to form into pillows, they must first flow down an escarpment where each flow is divided into individual streams. These thin streams then interact with the lake waters to form log and pillow shapes. The pillow deltas are important evidence in delineating the history of Lake Idaho, because they mark the interface at the time of their eruption between the air and the lake waters. Thus, because the basalt flows can be dated, the basalt deltas establish water levels in the lake for particular periods. The debris formed by the pillow deltas at their fronts is the likely source for some of the basaltic tuffs intercalated with the lake sediments.

North Area Units

Qrs Basalt of Rattlesnake Springs (Pleistocene) — The highest elevation rim and surface on the north side of the Snake River canyon in the C.J. Strike Dam, Bruneau Dunes, and Bruneau quadrangles. The unit appears to be entirely subaerial. Flows in hand sample contain abundant, medium to large plagioclase and olivine phenocrysts, some in clumps.

Qstr Basalt of Strike Dam Road (Pleistocene) — Located on the northwest side of the Snake River canyon in the C.J. Strike Dam and Grand View quadrangles. In hand sample the flows contain only abundant, medium to large olivine phenocrysts. A roadcut on the Strike Dam Road near the canyon rim has exposed an area of pillowing at the south end of the unit. In another exposure along the west canyon rim, the unit is underlain by a thin-bedded cinder layer. The flows were perhaps erupted from Little Joe Butte in the Little Joe Butte quadrangle to the northwest outside the mapped area.

QTsim Basalt of Simco Road (Pliocene or Pleistocene) — Located on both the north and south rims of the Snake River canyon in the C.J. Strike Dam and Bruneau quadrangles. In several places at its edge, the unit formed thick and extensive pillow deltas. Because the flows are generally horizontal and the areas of pillowing are not continuous, the flows in this unit probably were interacting with bodies of water, either Lake Idaho or perhaps smaller post-Lake Idaho lakes.

QTcrf Basalt of Crane Falls (Pliocene or Pleistocene) — Only exposed over a small area on the north wall of the Snake River canyon in the C.J. Strike Dam and Bruneau quadrangles. We do not have a sample of this basalt for comparison, so its hand sample lithology is unknown. Thus, the unit may be correlative with another basalt unit exposed elsewhere in the canyon.

Tcg Basalt of Chalk Gulch (Pliocene) — Located on both sides of the Snake River in the Bruneau Dunes quadrangle. The unit also continues outside the area to the east in the Indian Cove quadrangle. In its eastern exposure in the mapped area, the unit contains numerous basalt flows and is up to 200 feet (61 m) thick. It is water affected to some degree over most of the exposure and in several places also has pillowed basalt at its base. These features suggest that the unit interacted with a standing body of water. In some places along the rim of the Snake River, where the river makes a steep-walled canyon, the Bonneville Flood waters have stripped the overlying sediments from the unit's surface. In other places, the flood eroded into and created channels in the uppermost flows. Thus, the flood both changed the thickness of the unit and in some areas made it appear to be more than a single unit. In hand sample the flows contain abundant to very abundant, medium to large plagioclase phenocrysts as well as varying amounts (none to some) of olivine crystals.

Tfly Basalt of Flying H Ranch (Pliocene) — Located north of the Snake River canyon in Bruneau Dunes quadrangle. The unit overlies the basalt of Chalk Gulch. At its westernmost edge the flows of the unit make a fairly large pillow delta. Just south of the delta, pieces of the pillowed flows are incorporated into a nearby exposure of *QTgqb*. In addition, on its west edge the deposit is beneath an area of *QTgq*. In hand sample the flows contain some to abundant, medium to small plagioclase phenocrysts.

Tcan Basalt of Canyon Creek (Pliocene) — The lowest unit in elevation in the sequence of units extensively exposed along the rims of the Snake River canyon in the Bruneau, C.J. Strike Dam, and Grand View quadrangles. The unit is pillowed in only one place on the west edge in the Grand View quadrangle. In other areas it is water affected to some extent. Its south edge is irregular, suggesting that the present exposure may closely approximate the original flow margin. In all hand samples, the flows are essentially aphyric with some samples containing scarce to some tiny to small plagioclase phenocrysts.

Tgsm Basalt of Goldsmith Road (Pliocene) — Located on both sides of the Snake River canyon east and west of Idaho Highway 51 northeast of the town of Bruneau, as well as north and south of the Bruneau Narrows west of the town of Bruneau. The unit outcrops in the C.J. Strike Dam, Bruneau, and Bruneau Dunes quadrangles. Throughout its exposure the unit is extensively water affected. It also contains several areas of pillowing, one of which is near a basaltic tuff in the area of Wilkins Gulch on the north side of the Bruneau Arm of C.J. Strike Reservoir. West of Idaho Highway 51 in the lower canyon of Rattlesnake Creek in the Bruneau Dunes quadrangle, each flow within the unit has a pillowed base. The water-affected character of the flows meant that we could not always identify its phenocryst content in hand sample. However, in some samples the unit has some to abundant, small to large, felty plagioclase crystals. The size of the plagioclase phenocrysts seems to range from larger in the east to smaller in the west. In most samples the olivine crystals have been weathered out. Where visible, they are only small to medium in size.

Tkl Basalt of Katie Lane (Pliocene) — Only exposed in a small area on both sides of the Bruneau Narrows and east along the Bruneau Arm in the C.J. Strike Dam quadrangle. In two places, the unit makes an extensive pillow delta, which has shed detritus that looks very much like a basaltic tuff. Both the tuff and one area of the pillows contain significant quantities of *Tgq* cobbles.

Tdix Basalt of Dixie Road (Pliocene) — Makes the bench on the north side of the Snake River, west of C.J.

Strike Dam in the C.J. Strike Dam and Grand View quadrangles. The base is pillowed in at least two places. In hand sample the flows contain varying amounts of olivine crystals including rare, very large crystals.

South Area Units

Twc Basalt of Winter Camp Butte (Pliocene) — Covers much of the Pence Butte and Pot Hole Butte quadrangles and smaller parts of the Austin Butte and Crowbar Gulch quadrangles. The flows in this widespread unit erupted from the Winter Camp Butte volcano in the southeast corner of the Pot Hole Butte quadrangle. The unit is the youngest on the south side of the area, and therefore it covers much of the underlying stratigraphy. Over most of its exposure the edges of the flows are pillowed and define the slope break between the basalt plateau that continues south to Nevada and the Lake Idaho sediments to the north. The unit lies both above and below *Tgq*. The point where its bottom flow forms a pillow delta probably marks one of the highstand shorelines of Lake Idaho.

Tphb Tuff of the Pot Hole Butte volcanic complex (Pliocene) — Erupted from at least three vents collectively called Pot Hole Butte. The deposits of this hydroclastic unit are in the Pence Butte and Pot Hole Butte quadrangles. Because of posteruption erosion, loess cover, and the fine-grained character of the tuff, we were unable to locate the exact boundaries of this unit. Features of the principal vent area are described in Jenks and Bonnichsen (1989). The distal, layered parts of the tuff are exposed to the south and east of the main vent area, in draws cut below the edge of the basalt of Winter Camp Butte. Some of the subaerial-appearing spatter deposits, which are the uppermost rim in the main vent area, contain in hand sample very abundant large plagioclase phenocrysts.

Tbrc Basalt of Browns Creek (Pliocene) — Covers the surface north and east of Pence Butte in the Pence Butte and Pot Hole Butte quadrangles. This relatively thin unit nonetheless is important because, with the underlying *Twc*, its edge forms the slope break between the sediments to the north and the basalt plateau to the south. In hand sample the lithology of its flows changes from containing a few scattered, small to medium plagioclase phenocrysts in the west to having a general aphyric appearance in the east.

Tpeb Basalt of Pence Butte (Pliocene) — Located on the east side of the area in the Pence Butte and Pot Hole Butte quadrangles. The flows of most exposures of the unit formed large pillow deltas intercalated with the Idaho Group sediments. The volcano that erupted the unit is Pence Butte on the south side of the Pence Butte quadrangle. The U.S. Air Force presently uses the butte as its principal target on the Saylor Creek Bombing Range. In all of its exposures, the flows in hand sample contain large, rosette-type clumps of large plagioclase and olivine phenocrysts.

Tlbbu Upper basalt of Lower Black Butte Crossing (Pliocene?) — Located in a small area on the east side of Pot Hole Butte quadrangle, the unit also extends into the adjacent Black Butte West quadrangle. The volcano from which these flows erupted appears to be hill 3608 in the north part of Black Butte West quadrangle. In hand sample the flows range in their phenocryst content from abundant large plagioclase and olivine to sparse plagioclase.

Tlbbl Lower basalt of Lower Black Butte Crossing (Pliocene?) — Exposed in only a small area in the bottom of Pot Hole Canyon on the east side of Pence Butte quadrangle. The unit extends to the north down the drainage in the Pot Hole Canyon quadrangle. The flows have an inclined, scoriaceous and possibly pillowed aspect and in hand sample are aphyric.

Twfb Pillow basalt of West Fork Browns Creek (Pliocene) — Located in the bottom of the West Fork of Browns Creek drainage at the intersection of the Hot Spring, Pence Butte, and Pot Hole Butte quadrangles. The unit is pillowed throughout its exposure and is one of the best three-dimensional exposures of a pillow delta that we have found in the Snake River Plain. In hand sample the basalt flows contain numerous large plagioclase phenocrysts, in some samples as clumps or rosettes.

Tsog Basalt of Seventy One Gulch (Pliocene) — This volcano and its related dike deposits are in the south part of the Hot Spring quadrangle. The volcano is hydroclastic, and some of the flows from the dike are pillowed. Adjacent to the volcano the dike's exposure shows an intrusion of the lava into wet sediments. Most of the deposits in the volcano itself are cinders.

Tcuf Basalt of Curlew Flat (Pliocene) — Located in only a small area on the east side of the Bruneau River canyon in Crowbar Gulch quadrangle. The unit is directly below the surrounding pillow delta of the basalt of Winter Camp. The unit is probably correlative with another unit within this part of the area, but its limited exposure prevents direct correlation. In hand sample the unit is diktytaxitic to massive with sparse to some large clumps and crystals of olivine and sparse large plagioclase phenocrysts.

Thc Basalt of Hot Creek (Pliocene) — Located over a large area in the lower parts of the Bruneau River canyon and in Hot Creek. The unit is exposed in the Broken Wagon Flat, Sugar Valley, Hot Spring, and Crowbar Gulch quadrangles. It is correlative with one of the upper units in the *Tbru* composite unit. Throughout much of its exposure, but particularly in its northern part, the basalt of Hot Creek is extremely water affected. Thus, in many places, it either looks like a brown sediment slope or has been almost completely eroded, leaving only isolated exposures of less affected basalt. It is difficult to see the phenocryst assemblage of the flows in hand sample. It is mostly aphyric, but some samples also contain plagioclase phenocrysts, and others olivine crystals.

Tind Basalt of Indian Bathtub (Pliocene) — Located in the Hot Creek drainage and the lower Bruneau River canyon in the Broken Wagon Flat, Sugar Valley, Hot Spring, and Crowbar Gulch quadrangles. Throughout its exposure, the unit is above the thickest of any of the sediment layers intercalated with the basalt units exposed in the lower Bruneau River canyon. This sediment layer appears to vary in thickness over short distances. The unit also changes in thickness within its area of exposure. It ranges from only a single flow, where it becomes correlative with *Tbru* south of the confluence of Crowbar Gulch with the Bruneau River, to several flows that make a thick unit in the area surrounding the confluence of Hot Creek with the Bruneau River. The unit may have been emplaced during or shortly after a fluctuation in lake levels (see previous *Hot Springs* discussion). The phenocryst content varies in hand sample throughout the area of exposure. This variability can be explained in one of two ways. First, unlike the other basalt units, the flows of this unit may simply vary in their phenocryst content. Second, what we have assumed is straightforward stratigraphy is really more complex, and thus, some of the samples may belong to other units.

Tbuc Basalt of Buckaroo Dam (Pliocene) — Located in the lower parts of Hot Creek and the Bruneau River in the Hot Spring and Crowbar Gulch quadrangles. The unit is part of the sequence of basalt units that form the walls of the lower Bruneau River canyon. It is probably correlative with one of the units in the *Tbrm* composite unit. It is water affected throughout much of its exposure and is beneath a silty clay sediment. The flows in hand sample contain medium to large olivine crystals as well as very sparse large plagioclase.

Tharu Upper basalt of Harris Dam (Pliocene) — Located in the lower part of the Bruneau River canyon in the Hot Spring and Crowbar Gulch quadrangles. The unit probably is correlative with one of the subunits within the *Tbrm* composite unit. It is not generally as extremely water affected as the overlying units. In hand sample the flows contain abundant, medium to large plagioclase phenocrysts and some small olivine crystals.

Tharl Lower basalt of Harris Dam (Pliocene) — The lowest unit in the downstream end of the Bruneau River canyon in the Hot Spring and Crowbar Gulch quadrangles. The unit probably is part of the sequence of units in the *Tbrm* composite unit exposed to the south. In hand sample it is water affected and felty, containing numerous small plagioclase phenocrysts and some small olivine crystals.

Tcro Basalt of Crowbar Gulch (Pliocene) — The uppermost unit in the area of Crowbar Gulch in the Crowbar Gulch quadrangle. Except for a subaerial exposure in the upper part of the gulch drainage, the unit is very water affected throughout its exposure. In appearance, stratigraphic position, and elevation, therefore, it is similar to the basalt of Hot Creek. However, it differs in phenocryst content. The flows are not aphyric like *Thc* but are slightly diktytaxitic with varied sizes and amounts of plagioclase phenocrysts, some in clumps, and with abundant to scattered olivine crystals.

Tbru Upper basalt of Bruneau River (Pliocene) — Located in the Bruneau River canyon in the Crowbar Gulch quadrangle, north of the Miller Water draw and south of Crowbar Gulch. The unit is a composite, consisting of a sequence of three to four subunits exposed in the upper part of canyon. It is separated from *Tbrm* by a slope break that, where exposed, contains a significant thickness of sediment. In the part of the canyon upstream from the Bruneau Scenic Overlook, some of the upper subunits within this composite unit are extremely water affected.

Tbrm Middle basalt of Bruneau River (Pliocene) — Located within the same area as the upper basalt of Bruneau River in the Crowbar Gulch quadrangle. This is the middle composite unit exposed in the canyon and also contains three to four subunits of basalt flows, each separated by a thin sediment. It is above a covered slope break that probably marks the position of a section of sediments.

Tbrl Lower basalt of Bruneau River (Pliocene) — The lowest sequence of units within the Bruneau River canyon in the Crowbar Gulch quadrangle, north of Miller Water draw and south of Crowbar Gulch. The composite unit forms the shear cliff in the bottom of the canyon. The unit contains four or five individual subunits, depending on the depth of the canyon. Its subunits appear to be less rubbly than any of the subunits in the other two overlying composite units. The competent appearance suggests that all these subunits may have been emplaced subaerially. The subunits are separated from one another by very thin, red sediment layers.

Tbr Basalt of Bruneau River (Pliocene) — Located in the Austin Butte quadrangle between the Miller Water draw and the south edge of the area. The composite unit is above the basalt of Austin Butte and below the basalt of Miller Water and the basalt of Winter Camp. Over most of its exposure, the unit contains only one or two subunits. However, in the area of the Miller Water draw and across from the Austin Butte volcano, it contains as many as five subunits. The contact of this unit with the sediments exposed northwest of Austin Butte is uncertain and therefore queried.

Tmw Basalt of Miller Water (Pliocene) — Exposed on both sides of the Bruneau River canyon in the area around Miller Water draw in the Austin Butte and Crowbar Gulch quadrangles. In hand sample the unit has a diktytaxitic texture with moderate amounts of large plagioclase crystals and some olivine crystals. Both chemically and petrographically, the unit appears to be similar to *Twc*. However, stratigraphic relations require that the units be separate.

Troc Basalt of Rock Lake (Pliocene) — Located in the south part of the area west of the Bruneau River in Austin Butte quadrangle. The unit is exposed in only two small areas. In hand sample the flows are felty with abundant medium to large plagioclase and sparse small olivine crystals.

Tbib Basalt of Big Bend (Pliocene) — Located in the southern part of the Austin Butte quadrangle on the west side of the Bruneau River. The volcano that erupted the flows is to the south of the area on the north side of Sheep Creek. Within the mapped area hand samples are nearly aphyric with sparse small plagioclase phenocrysts. Elsewhere, samples from outside the area vary in content. Some samples contain large olivine crystals and small plagioclase laths while others have sparse, very large, typically equant plagioclase phenocrysts.

Ttwi Basalt of Twin Butte (Pliocene) — Three unconnected exposures: the prominent Twin Butte location, a large area in the Austin Butte quadrangle, and a single small exposure in the northeast corner of the Table Butte quadrangle. All exposures have been displaced by postemplacement faults. At its thickest exposure, the unit contains only two subaerial flows. In hand sample the flows contain only abundant, medium to large olivine phenocrysts and no visible plagioclase crystals.

Tsal Basalt of Salvador Lake (Pliocene) — The most extensively exposed unit in the northwest part of Austin Butte quadrangle. In hand sample the unit contains large and numerous clumps of olivine crystals with some large plagioclase phenocrysts. One of the subunits in the *Tbr* composite unit probably is a continuation of the flows of this unit.

Tab Basalt of Austin Butte (Pliocene) — One of the best exposed volcanoes in the area. The unit is in the Austin Butte quadrangle. The volcano is Austin Butte, located at the confluence of Clover Creek and the Bruneau River. The flows are exposed in three directions, to the north and south in the Bruneau River canyon and to the east in Clover Creek. The unit's thickness ranges from 40 feet to 400 feet (12-122 m), because its flows were emplaced directly on the irregular top of the underlying rhyolite lava flow. At the volcano the character of the flows varies up-section. The lower section is thicker and characterized by a few, fairly massive flows. The upper section contains as many as fifteen thin and very scoriaceous flows. In hand sample the flows contain clumps of plagioclase and olivine in a microcrystalline matrix.

Ttab Basalt of Table Butte (Pliocene) — This small exposure in Table Butte quadrangle is one of the most enigmatic basalt units in the area. A subaerially emplaced unit, its exposure is nearly circular in plan view. On its north side it rests directly on the rhyolite of Sheep Creek. On its south side it rests on at least 20 feet (6.1 m) of fine-grained sediments. Flow-layering is a prominent feature within individual flows. The exposure does not appear to be a volcanic vent. Instead its flows have characteristics that we have in other units associated with the more distal parts of flows. Proximity suggests that the exposure at Table Butte may be related to two other isolated basalt exposures to the southwest. In hand sample the flows contain abundant, small plagioclase phenocrysts.

Tbwf Basalt of Broken Wagon Flat (Pliocene) — Located in the Hot Creek drainage in the Broken Wagon Flat quadrangle. Even though the exposures suggest a single unit, its phenocryst content is varied. In the Hot Creek drainage, the basalt flows in hand sample are diktytaxitic or felty with abundant, medium to large plagioclase phenocrysts. In exposures to the west the lithology is water affected and, in hand sample, appears to be nearly aphyric with some medium-sized plagioclase phenocrysts. Thus, the unit may actually need to be further subdivided into several units from more than one source.

Tbgr Basalt of Blackstone Grasmere Road (Pliocene) — Located in the bottom of the Hot Creek drainage in the Broken Wagon Flat quadrangle. In some areas it is water affected; in others, it appears to have been subaerially emplaced. Its lithology in hand sample is abundant large olivine crystals with varied amounts and sizes of plagioclase phenocrysts.

Tsot Basalt of South Top (Pliocene) — Two isolated outcrops in the Sugar Valley and Broken Wagon Flat quadrangles. The unit is entirely water affected and enclosed within the Idaho Group sediments. It is probably correlative with one of the units in the Hot Creek drainage to the east.

Thtc Basalt of Horse Trap Corral (Pliocene) — Makes the flat and rim along and east of Idaho Highway 51 in the Broken Wagon Flat and Hole In Rock quadrangles. The outline and extent of the unit suggest that it flowed north from the area of a small hill surrounded by the 3600-foot contour in SW1/4SW1/4 sec. 32, T. 8 S., R. 5 E. However, our traverse in that area did not prove conclusively whether this hill is a vent. At its edges the flows are extensively water affected. In hand sample it is a dense and aphyric lithology with a few olivine phenocrysts, some in clumps, and very sparse plagioclase phenocrysts.

Tsug Basalt of Sugar Creek (Pliocene) — Located on the east side of the Sugar Creek drainage in the Broken Wagon Flat quadrangle. Throughout its exposure the flows are extremely water affected and above a red fine-grained sediment layer. An oolitic limestone continues for a short distance at the same elevation at the unit's north edge. At its south edge, a small area of reefal limestone is above as well as at the same elevation. The unit is probably correlative with one of the basalt units exposed in the Hot Creek and Bruneau River drainages.

Tww Basalt of Windy Well (Pliocene) — Floors the bottoms of the draws east of the Sugar Creek drainage in the Broken Wagon Flat and Hole In Rock quadrangles. The unit is water affected in some areas. It is probably correlative with one of the units exposed in the Hot Creek and Bruneau River drainages. Throughout its exposure, hand samples of the flows contain numerous small plagioclase phenocrysts.

Tmbr Basalt of Missile Base Road (Pliocene) — Located in the bottom of the Sugar Creek drainage in the northwest part of the Broken Wagon Flat quadrangle. Throughout its exposure, the unit is extremely water affected. It is above red "baked" sediment, which in one area includes a small lens of pebble gravel. The basalt of Missile Base Road may be correlative with other basalt units in the Sugar Creek drainage and is probably correlative with units exposed in the Hot Creek drainage and Bruneau River canyon.

Tbla Basalt of Black Rocks (Pliocene) — Located to the west of Idaho Highway 51 in the southern part of the Little Valley quadrangle. The unit is extremely water affected throughout its exposure. Thus, in many areas only the bottom flow and its underlying red sediment remain of what was originally a fairly thick unit. In areas of less affected basalt, the unit in hand sample is olivine phyric with some large single crystals as well as clumps. Since no nearby source exists for this unit, we assume that it is the westward extension of one of the basalt units exposed in the Sugar Creek, Hot Creek, and Bruneau River drainages.

Tdea Basalt of Deadman Gulch (Pliocene) — Exposed over a fairly large area in the drainages just west of Idaho Highway 51 in the Hole In Rock quadrangle. Except in its farthest southern exposures, the unit is extremely water affected. In one place the top of the unit's upper flow contains a breccia mixed with the overlying silts. The bottom flow of the unit rests on a red sediment layer. In at least two areas, the unit has been completely eroded away, with nothing remaining but the underlying red sediment layer. Less affected hand samples contain some small plagioclase phenocrysts. The phenocryst content of the unit, the widespread nature of its flows, and its proximity to the basalt of Windy Well to the east in the Sugar Creek drainage strongly suggest that these two units may be correlative. Presumably, it is also correlative with one of the basalt units in the Hot Creek drainage and the Bruneau River canyon.

Tals Basalt of Al Sadie Ranch (Pliocene) — Exposed in the bottoms of the small grabens at the adjacent corners of the Hole In Rock, Little Valley, and Chalk Hill quadrangles. The unit is in the area between, and east and west of, the Big and Little Jacks Creek drainages. Throughout its exposure the unit is extremely water affected. In some places very little of the unit is still intact above the red sediment layer. Everywhere the unit is enclosed within a section of fine-grained Idaho Group sediments. In hand sample the flows have a phenocryst content that ranges from a few individual, small plagioclase phenocrysts to clumps of olivine and small plagioclase crystals.

Thir Basalt of Hole In Rock (Pliocene) — The volcano for this unit is in the southwest corner of the

Hole In Rock quadrangle. Its flows extend to the north of the volcano within a small area next to Wickahoney Creek in the Hole In Rock and Big Horse Basin Gap quadrangles. The flows evidently followed a paleodrainage, filling it and overlying a *Tgq* layer. All hand samples from the flows contain plagioclase phenocrysts that range in abundance from sparse to plentiful and in size from small to large. This range may indicate a compositional variability in the unit itself or the presence of more than a single unit.

Twhc Basalt of Wickahoney Creek (Pliocene) — Only outcrops in a very small area in the adjacent southern corners of the Hole In Rock and Big Horse Basin Gap quadrangles. Since the unit is beneath the basalt of Hole In Rock, it also has presumably followed a paleotopographic low and flowed north from sources to the south. Outside the mapped area, the unit is composite and contains at least two subunits separated by a sediment layer. Within the area the unit contains a single sequence of flows with no intercalated sediment.

Twt Basalt of Whickney Tree Reservoir (Pliocene) — Erupted from a volcano (hill, elevation 6062) on the west edge of the O X Lake quadrangle. In some areas its flows appear to have followed paleoslopes. The flows have also been cut and displaced by numerous postemplacement faults.

Tol Basalt of O X Lake (Pliocene) — Located in the area surrounding the O X Prong of Little Jacks Creek in the southeastern part of the O X Lake quadrangle. The unit probably erupted from a volcano to the south of the area. Our examination of a single hand sample suggests only that the flows have abundant phenocrysts.

Rhyolite Lava Flows

A series of rhyolite lava flows are in the southern part of the area. A single large unit, the rhyolite of Sheep Creek, dominates the landscape in the southeastern part. Other flows are exposed in the upper canyons of the Big Jacks, Little Jacks, Shoofly, and Poison creeks, and their tributaries.

Bonnichsen (1982) and Bonnichsen and Kauffman (1987) described the rhyolite lava flows in detail; some of the characteristics of individual units are taken from these reports. The general rhyolite flow characteristics are as follows. Each lava flow has three distinct internal zones: a lower, a middle, and an upper. The lower zone is made up of red and black flow breccia and is up to 30 feet (9 m) thick. It may also have from 1 to 3 feet (0.3-1.0 m) of flow-layered vitrophyre (black, glassy, noncrystalline rhyolite). The lower zone grades vertically into a middle zone of massive, devitrified rhyolite (red, crystalline). In canyon exposures these devitrified middle zones contain vertical shrinkage joints that propagated from the upper and lower zones of the flow. The areas of these joints are commonly easy to locate because they form prominent cliffs. Where the two joint surfaces meet, however, the flow weathers more easily to a steep rubble-covered slope. This gives the flows their characteristic "two-tiered" appearance. The upper zones are flow layered and extensively folded, especially toward their uppermost surface. This zone contains both devitrified, brecciated areas and vitrophyre sections. Some of the rhyolite flows are underlain by thin air-fall ash deposits. The ends of the flows are thick and bulbous with large flow lobes.

Tru Rhyolite, undifferentiated (Miocene) — Located as horsts separated from the main parts of the named rhyolite units by sediment-filled grabens. The exposures are in two separate areas: east and west of Idaho Highway 51 in the Broken Wagon Flat, Little Valley, and Hole In Rock quadrangles; and east of the Mud Flat Road in the Perjue Canyon quadrangle.

Thb Rhyolite of Horse Basin (Miocene) — Exposed between and east of the Big and Little Jacks Creek canyons in the Hole In Rock, Little Valley, Chalk Hills, and Big Horse Basin Gap quadrangles. In its more northern exposures the unit contains hundreds of feet of rhyolite breccia intercalated with dikes and sills of unbrecciated and jointed devitrified rhyolite. At its southern edge the unit apparently flowed against a northeast-facing paleoescarpment that has been completely eroded away. In fact, the flow may have been erupted from a buried northwest-trending fissure near its southern edge. In some places the unit is underlain by 0.3 to 3.0 feet (0.1-1.0 m) of air-fall ash. Plagioclase and pigeonite phenocrysts are more abundant in this lava flow than in others in the region. The unit has normal paleomagnetic polarity.

Tsfc Rhyolite of Shoofly Creek (Miocene) — Located in the southwestern part of the mapped area in the O X Lake and Perjue Canyon quadrangles. No information about its internal or petrographic characteristics is available at this point in our research.

Tsc Rhyolite of Sheep Creek (Miocene) — The largest single unit within the mapped area, it is in the Crowbar Gulch, Broken Wagon Flat, Hole In Rock, Table Butte, Austin Butte, and Big Horse Basin Gap quadrangles. This enormous lava flow is exposed over a broad area between the Bruneau River and the Big Jacks Creek canyons. It also extends for many miles to the south outside the area and has an overall extent of approximately 400 square miles (1,000 km^2). The unit mainly contains phenocrysts of plagioclase, augite, pigeonite, and opaque oxides, but it also has very sparse, tiny quartz crystals. Hart and Aronson (1983) dated a sample of this unit at 9.88 ± 0.46 m.y. using the whole rock K-Ar method. The unit has normal paleomagnetic polarity.

Tpc Rhyolite of Perjue Canyon (Miocene) — Located in the Perjue Canyon, O X Lake, and Big Horse Basin Gap quadrangles and underlies a large area between Big Jacks Creek canyon and the western edge of the area. Phenocrysts are principally plagioclase and pigeonite. The unit has reverse paleomagnetic polarity.

Thg Rhyolite of Halfway Gulch (Miocene) — Exposed in and between the large ravines in the Perjue Canyon, O X Lake, and Big Horse Basin Gap quadrangles just south of the major Snake River Plain margin faults. Parts or all of this unit may be correlative with the rhyolite of Tigert Spring, exposed to the east in the Little Jacks Creek canyon.

Tbtc Rhyolite of Between The Creeks (Miocene) — Located only in a small part of the western edge of the area in the bottom of Perjue Canyon in the O X Lake quadrangle. The unit also is exposed to the west of the area. Although the base is not exposed in the area, to the west it rests on a tilted surface of Eocene volcanics.

Tts Rhyolite of Tigert Spring (Miocene) — Located in and between the canyons of the Big and Little Jacks Creeks in the O X Lake and Big Horse Basin Gap quadrangles. Although the unit is sporadically exposed on the west side of the Little Jacks Creek canyon, the creek follows its approximate western and southwestern margins. The phenocryst assemblage is sanidine, plagioclase, pigeonite, and augite. The unit has reverse paleomagnetic polarity.

Top Rhyolite of O X Prong (Miocene) — Exposed only in the walls of the Big and Little Jacks Creek canyons in the southwestern part of the area in the O X Lake and Big Horse Basin Gap quadrangles. In Little Jacks Creek the unit forms a persistent thin upper cliff that distinguishes it from the other rhyolite units in the area. The unit contains sanidine, plagioclase, and pigeonite phenocrysts. It shows erratic paleomagnetic polarity.

Trc Rhyolite of Rattlesnake Creek (Miocene) — Located in the bottom of the Little Jacks Creek canyon in the O X Lake and Big Horse Basin Gap quadrangles. The base is not exposed. In addition its characteristics are ambiguous as to whether the unit is a lava flow or a welded tuff. Petrographically, it is similar to the rhyolite of O X Prong above it. The unit has normal paleomagnetic polarity.

Older Volcanic Units

Tev Eocene volcanics — Located on the southwest side of the area on both sides of the Mud Flat Road in the Perjue Canyon quadrangle. Ekren and others (1981) correlated the units with the Challis Volcanics that are extensively and widely exposed over south-central Idaho. Neill (1975) reported a whole rock K-Ar date of 43.6 ± 0.8 m.y. for the exposures on the west side of Poison Creek at the extreme western edge of the area. The unit is a red, pink, tan, brown, white, or green rhyodacite. It is somewhat more phenocryst-rich in hand sample than the overlying rhyolitic rocks, and according to Ekren and others (1981) contains quartz, alkali feldspar, plagioclase, biotite, hornblende, and opaque oxides. Another distinguishing feature of the unit is its fairly extensive inclusions of jasper. Clasts eroded from this unit are a characteristic lithology in the gravels above and within the Idaho Group sediments to the north.