Geologic Map of the Northern and Central Parts of the Idaho National Engineering and Environmental Laboratory, Eastern Idaho

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INTRODUCTION

The Idaho National Engineering and Environmental Laboratory (INEEL), formerly known as the Idaho National Engineering Laboratory (INEL), is a U.S. Department of Energy nuclear research facility opened in 1949 (Bartholomay and others, 2002). Chemical and radiochemical wastes from various nuclear research facilities have been discharged to infiltration ponds on the INEEL site. Injection wells were used for waste disposal until 1983. The present study stems from the need to develop a waste remediation plan for the Test Area North (TAN) facility in the central part of the map area. Geologic maps like this one are part of the first-order characterization of any part of the earth's surface. As such, they are required before any validated models for the stratigraphic architecture of the shallow subsurface can be assembled.

This map reinterprets the regional framework of basaltic volcanism and fluvial-eolian-lacustrine sedimentation in part of the Snake River Plain volcanic province. The framework, based on this and other geologic maps and on data from more than 300 boreholes at the INEEL, provides data for evaluating hydraulic properties of the vadose and saturated zones, for modeling the movement of ground water in the subsurface, and for appraising volcanic hazards for the INEEL. Characterizing the surface geology defines the materials in the vadose zone and is necessary for assessing the geometry, composition, porosity, and permeability of the rocks that host and control the regional ground-water flow system. Related studies on the subsurface geology of the INEEL by researchers contracted by the Department of Energy and scientists at various academic institutions and the U.S. Geological Survey (USGS) are contained in the Geological Society of America's Special Paper 353 (Link and Mink, 2002).

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GENERAL DISCUSSION

The map revises part of the previous geologic map of the INEL by Kuntz and others (1994). The surficial deposits in the Big Lost River Sinks and Test Area North (TAN) areas have been studied by Geslin and others (2002), Mark (1999), Mark and Thackray (2002), and Kauffman and Geslin (1998). The map contains new mapping of the Howe Point area of the southern Lemhi Range by Hodges and Rodgers (1999). The geology of the basalt lava fields of the Lava Ridge area is revised on the basis of more detailed mapping by Kuntz and by new paleomagnetic and geochronologic studies by Champion and Lanphere.

SURFICIAL DEPOSITS

A major focus of the new work presented on the map is the subdivision and hydrologic properties of surficial deposits in the Big Lost River Sinks area of the INEEL. The Sinks are part of a Pliocene to Holocene sedimentary basin called the Big Lost Trough (Geslin and others, 1999, 2002; Bestland and others, 2002), which is silled by volcanic uplands on the northeast, southeast, and southwest sides. Water and sediment from the Big and Little Lost rivers are ponded in the Big Lost Trough.

Climate is the first-order control on Pleistocene and Holocene sedimentation in the Big Lost Trough. During Pleistocene glacial periods, braided fluvial sediments prograded into the basin and interfingered with muddy lacustrine sediment deposited in late Pleistocene Lake Terreton and its precursors. During interglacial periods, infiltrative playa and aeolian sediments were deposited. The Big Lost Trough has existed as an underfilled sedimentary basin since the first basaltic eruptions of the Lava Ridge-Hell's Half Acre volcanic rift zone about 2.3 Ma formed its northeastern margin (Blair, 2002).

Mark (1999) and Mark and Thackray (2002) determined the sedimentologic and hydrologic properties of surficial sediments in the Big Lost River Sinks area. The bulk of the sediment has low hydrologic conductivity, except in linear bodies of sandy fluvial sediment and a unique sediment type, which forms lunettes or aeolian dunes on the margins of playas. These lunettes are composed of sand-sized aggregates of clay particles which, because they are tightly cemented, have the saturated hydrologic behavior of sand even though they are composed of clay minerals.

BASALT LAVA FIELDS AND FLOWS

Much of the western and eastern parts of the INEEL are underlain by late and middle Pleistocene basaltic lava flows, all of which have normal magnetic polarity and thus are younger than about 780 Ka. Many of the lava fields in the south-central, southwestern, and southeastern parts of the INEEL area are 200 to 400 Ka, based on paleomagnetic studies and K-Ar dating. The northwestern part of the INEEL, specifically the Lava Ridge area, contains some of the oldest exposed basaltic lava flows in eastern Idaho. The latter flows have reversed magnetic polarity; thus they are older than about 780 Ka, and available K-Ar ages are 800 Ka to 1.2 Ma.

The Crater Butte (*Qbc*$_1$) and Microwave Butte (*Qbc*$_2$) lava fields are the two largest lava fields on the map, but much of their areas and each of their vent areas are located beyond the map's margins (see Kuntz and others, 1994). The Crater Butte lava field has a minimum area of 230 square km and a minimum volume of 3.4 cubic km. The Microwave Butte lava field has a minimum area of 260 square km and a minimum volume of 3.2 cubic km. The area and volume measurements for both lava fields are minimum values because younger flows or sediments cover distal parts of the lava fields. The other, older basaltic lava fields shown on this map and the lava fields in the subsurface probably have areas and volumes similar to those of the Crater Butte and Microwave Butte lava fields.

Most lava fields on the map consist of pahoehoe lava flows that spread radially from slot-shaped, fissure-controlled source vents. Lava was delivered from the vent areas to advancing flow fronts through lava tubes. The effect of lava tubes in lava flows in the subsurface has not been correlated with the movement of ground water but, in all likelihood, lava tubes contribute to local areas of very high hydraulic conductivity.

Some of the source vents for various lava fields on the map are aligned in linear arrays. The prime example is the northwest-southeast alignment of Teat Butte, Vent 4853, Vent 5171, and Vent 5305. Although most vents for the lava fields on Lava Ridge lie west of their present limit of exposure and are covered by alluvial and colluvial deposits (*Qco*, *Qcy*), the vents are apparently confined to a narrow belt along the eastern flank of the Lemhi Range. These two linear arrays are segments of the Lava Ridge-Hell's Half Acre volcanic rift zone (Kuntz and others, 1992).

On the basis of similar paleomagnetic inclinations and declinations (see map, the discussion of paleomagnetic data, and Table 1), the eruptions from Teat Butte, Vent 4853, Vent 5171, and two vents to the southeast of Vent 5171 (beyond the southern boundary of this map) occurred at approximately the same time, perhaps simultaneously. This inference suggests that an eruptive fissure-dike system more than 30 km long occurs in the subsurface along the central and southeastern parts of the Lava Ridge-Hell's Half Acre volcanic rift zone. The implications of such a dike-fissure system on the flow of ground water in the Snake River Plain aquifer are discussed in Kuntz and others (2002). Paleomagnetic data that contribute to these conclusions are discussed below and are given in Table 1.

Most lava flows consist of olivine and plagioclase microphenocrysts that are 1-3 mm in longest dimension. Typically, the microphenocrysts are set in a matrix of olivine, plagioclase, intersertal clinopyroxene, minor opaque minerals, and small amounts of glass. Largest crystals in the matrix are chiefly ≤1 mm. Flows of several lava fields in the area of the map possess distinctive textures. Flows of the Richard Butte (*Qbe_3*) and Circular Butte lava fields (*Qbe_1*) contain plagioclase phenocryst laths as long as 15 mm, and flows of the Antelope Butte (*Qbd_2*) and Vent 4862 (*Qbd_3*) lava fields contain single olivine phenocrysts as large as 4 mm and clots of olivine phenocrysts as large as 6 mm.

In the absence of named landmarks, spot elevations are used to identify various basaltic lava fields: e.g., *Qbd_3* is the Vent 4862 lava field and *Qbc_3* is the Vent 5313 lava field. The spot elevations may be found on U.S. Geological Survey 1:24,000 topographic map quadrangles that cover parts of the Idaho National Engineering and Environmental Laboratory. The relative ages of basalt lava-field units are designated alphabetically (e.g., *Qbc* is younger than *Qbd*). Numbers are used to identify lava fields within lava-field age units (e.g., *Qbc*, *Qbc_2*, *Qbc_3*) but because radiometric ages are not available, the numbers should not be inferred to imply relative age relations of lava fields.

RHYOLITIC AND SEDIMENTARY ROCKS ALONG THE SOUTHERN MARGIN OF THE LEMHI RANGE

A sequence of Tertiary rocks including fluvial-lacustrine sediments, basalt flows, and rhyolite tuffs is present at Howe Point in the southern Lemhi Range. McBroome (1981) first mapped this region and described several units, especially three upper units of rhyolite ignimbrite. McBroome (1981) and Morgan and others (1984) also provided ages of several volcanic units based upon K-Ar and fission track analyses. The map by McBroome (1981) showed numerous faults throughout Howe Point, structures that Rodgers and Zentner (1988) later investigated in more detail because of seismic hazard concerns related to INEEL. The mapping by Rodgers and Zentner (1988) at Howe Point is used here. This has produced some changes to the map by McBroome (1981): three new Tertiary rock units were identified below the upper ignimbrite units; many contacts for all units were shifted to correspond with their observed position; and most faults were eliminated because either field evidence was lacking or their offset was less than 10 m. The present map also contains revised unit descriptions for some units at Howe Point, based on Hodges and Rodgers (1999), and some new ages based on new Ar/Ar analyses by M.H. Anders and others (unpub. data).

PALEOMAGNETIC DATA

Magnetic polarity and remanent inclination-declination directions (Table 1) were determined for basaltic lava flows from surface sample sites within the map area. Several sites are near those of samples collected for K-Ar analyses. Details of the laboratory procedures for the paleomagnetic studies of the basalt are given by Champion and others (1988). The confidence limits on paleomagnetic field directions for the basalt flows are in general small, but they vary as a function of age, topography, and lightning-strike effects.

Paleomagnetic sites from the northern part of the map are fairly evenly divided between reversed polarity sites for the Matuyama Reversed Polarity Chron (older than 780,000 years) and normal polarity sites associated with the Brunhes Normal Polarity Chron (younger than 780,000 years). Although separated by 13 km of mostly alluvial sediment-covered terrain, the Circular Butte (*Qbe_9*) and Richard Butte (*Qbe_3*) flows record the same direction of remanent magnetization and have similar, unique petrographic characteristics, suggesting that these two lava fields formed at the same time, about 1,094 ± 86 Ka. The Antelope Butte (*Qbd_2*) and Vent 4862 (*Qbd_3*) lava fields have similar and uncommon remanent magnetic directions and are adjacent to one another, suggesting that they erupted simultaneously. The various lava fields of the Lava Ridge area are all reversed magnetic polarity, and they record five different remanent paleomagnetic directions, indicating that the area experienced a varied, relatively complicated volcanic history more than 780,000 years ago. This history is further complicated because only a few vent areas are exposed; most vents lie west of the areas of present exposure, and the vents are covered by alluvial and colluvial deposits that were shed off the east flank of the Lemhi Range. Four sites in the Lava Ridge area have the same remanent magnetic direction (-52º, 203º), and correlations between these exposures are based on the magnetic data and petrographic similarities.

Magnetic data have helped to unravel the volcanic history in the central and southeastern part of the map. The magnetic directions from six lava fields, four of which are on the map, that extend from Teat Butte southeast to vent 5313, show similarities one to another, suggesting that these lava fields (*Qbc_3*, *Qbc_4*, *Qbc_5*, *Qbc_6*) may have erupted at the same time and may form an eruptive fissure-dike system about 23 km long (Kuntz and others, 2002). Along the same trend are two vents (including vent 5305 on the map and another vent 6 km southeast of vent 5305) that have similar paleomagnetic directions; this direction is different from that for lava fields *Qbc_3*, *Qbc_4*, *Qbc_5*, and *Qbc_6*. The implication from this paleomagnetic data is that this volcanic rift zone (the Lava Ridge-Hell's Half Acre zone of Kuntz and others, 1992), from Teat Butte southeastward to the Hell's Half Acre lava field, has had two periods of volcanic activity, neither of which has been dated.

The Crater Butte (Qbc_1) and Microwave Butte (Qbc_2) lava fields record the same direction of remanent magnetization, raising the possibility that these young (about 290 Ka), large-volume eruptions may have erupted at the same time, although their vents are located about 45 km apart and do not lie on the same north-northwest trending zone. Therefore, they are not part of the same eruptive-fissure system.

AGES OF LAVA FLOWS

Only one new K-Ar age is shown on the map compared to the ages in Kuntz and others (1994). A new age of 292 ± 58 Ka (Table 2) for the Crater Butte lava field (Qbc_1) supercedes a previous K-Ar age of 519 ± 52 Ka (Kuntz and others, 1994).

Table 1. Laboratory-determined paleomagnetic data for surface samples of basaltic lava flows and rhyolitic tuffs in and near the Idaho National Engineering and Environmental Laboratory.

Field Number	Lava field name or label or map unit	Inclination	Declination	$\alpha 95$	Magnetic polarity
4B631#*	Crater Butte – Qbc_1	63.1°	342.1°	1.6°	N
B5536	Microwave Butte – Qbc_2	62.1°	342.4°	1.3°	N
4B691#*	Microwave Butte – Qbc_2	66.1°	343.2°	1.7°	N
4B895#	Teat Butte – Qbc_3	42.9°	11.4°	1.5°	N
4B907#	Qbc_4	38.3°	4.8°	0.8°	N
A9619#	Qbc_4	40.9°	6.0°	1.4°	N
345B8	Qbc_4	44.3°	5.9°	2.1°	N
465B8	Qbd_5	41.0°	2.8°	5.4°	N
381B8	Qbc_6	46.8°	2.4°	2.8°	N
357B8	Qbc_7	62.3°	13.2°	2.0°	N
369B8	Qbc_8	64.5°	12.7°	3.3°	N
B7085	Qbc_9	63.8°	28.7°	2.5°	N
4B679#	State Butte – Qbd_1	74.6°	18.0°	3.3°	N
B5488	State Butte – Qbd_1	75.4°	26.9°	2.1°	N
A9631#	Antelope Butte – Qbd_2	65.4°	328.4°	2.3°	N
B7109	Antelope Butte – Qbd_2	64.4°	334.9°	3.0°	N
A9643#	Qbd_3	58.8°	328.1°	1.9°	N
	Matuyama-Brunhes boundary				
B7037	Qbe_1	-53.0°	157.8°	1.5°	R
4B787#	Qbe_1	-47.2°	158.5°	2.1°	R
B7049	Qbe_2	-77.7°	199.0°	2.5°	R
B7025	Richard Butte – Qbe_3	-65.8°	194.0°	2.1°	R
B5500	Qbe_4	-56.0°	201.0°	2.4°	R
4B883#	Qbe_5	-50.6°	203.1°	1.7°	R
B7061	Qbe_5	-50.5°	203.9°	1.0°	R
B7097	Qbe_5	-52.2°	202.4°	1.1°	R
B7121	Qbe_6	-71.9°	161.1°	2.2°	R
4B775#	Qbe_7	-75.3°	223.7°	1.9°	R
4B799#	Circular Butte – Qbe_8	-67.6°	189.8°	2.8°	R
	Tbc+	77.2	203.5	8.1	N
	Tb+	66.5	18.5	3.3	N

#Paleomagnetic data for these sites published previously in Kuntz and others (1994).
*Paleomagnetic sites that lie beyond the margins of this map. See Kuntz and others (1994) for site localities.
+Data from Anders and others (1993).

Table 2. Potassium-argon data for samples of basalt from surface flows in the TAN area, INEEL.

Field number	Vent or Name	K_2O (wt. %)	$^{40}Ar_{rad}$ (mol/g x10^{-13})	$^{40}Ar_{rad}$ (%)	Sample age Ka	Flow age Ka	Magnetic polarity
91ILe-2	Crater Butte (Qbc_1)	0.556±0.001	1.984	1.3	248±78	292±58	N
			2.790	1.6	349±88		
84ILe-24	State Butte (Qbd_1)	0.584±0.004	4.875	1.77	579±130	579±130	N
84Ile-23	Qbe_1	0.496±0.001	5.770	7.12	807±55	807±33	R
			6.248	7.82	874±57		
			5.279	6.74	738±58		
84ILe-22	Qbe_5	0.510±0.003	6.893	2.42	939±154	939±154	R
84ILe-2	Circular Butte (Qbe_8)	0.678±0.003	11.87	9.61	1,216±50	1,094±86	R
			10.18	6.9	1,043±62		
			8.992	5.1	921±70		

DESCRIPTION OF MAP UNITS

QUATERNARY

Alluvial Deposits

Alluvial deposits include Holocene and late Pleistocene sediments in fluvial channel, braid-plain, and overbank environments related to Big Lost River, Little Lost River, and Birch Creek. Relative age subdivisions of alluvial deposits are based on field relationships observed on aerial photos. Map boundaries and descriptions largely follow Scott (1982) and Kuntz and others (1994).

Fluvial sediments belong to two primary divisions: fluvial channel and braid-plain (lateral accretion deposits) and overbank (vertical accretion deposits). Channel and braid-plain sediment is poorly sorted to very poorly sorted; grains are angular to subrounded, and grain size ranges from sandy silt to cobbles. Deposits commonly contain cobbles and gravel in a silt to coarse-grained sand matrix. Deposits are finer along the distal reaches of the streams and in braid-plain environments; deposits are coarser on fans at the mouths of the Big Lost River, Little Lost River, and Birch Creek valleys. Sedimentary structures include trough cross bedding, tabular cross bedding, asymmetrical ripples, and graded beds.

Overbank deposits are located along the Big Lost River system and are typically silt-rich and moderately to poorly sorted. Grain size ranges from clay to coarse sand (Bartholomay and others, 1989). Sedimentary structures include mud cracks, trough cross stratification, and asymmetrical ripples. Bioturbation by vertebrates, arthropods, and vegetation is common.

Qas—Modern stream channel deposits (Holocene). Sand, pebble gravel, silt, and clay; locally humic in poorly drained areas. Subject to flooding; equivalent to unit *Qmy* of Kuntz and others (1994).

Qay—Young alluvial deposits (Holocene). Pebble and cobble gravel to pebbly sand; minor sand. Upper 0.5 to 2 m generally includes aeolian sand and silt. Forms terraces in southern part of map area. Includes units *Qmp*, *Qmt*, and *Qmtf* of Kuntz and others (1994).

Qam—Moderately old alluvial deposits (Holocene and upper Pleistocene). Lithologically similar to unit *Qay* and differentiated from *Qay* on the basis of higher geomorphic position and greater degree of soil development. Unit *Qam* has loess cover over 1 m thick and contains at least one buried soil. Includes unit *Qmo* of Kuntz and others (1994).

Qao—Very old alluvial deposits (upper Pleistocene). Lithologically similar to units *Qay* and *Qam*. Forms highest terraces with greatest soil complexity. Mapped with aerial photographs. Included with unit *Qmo* by Kuntz and others (1994).

Alluvial and Colluvial Deposits

Alluvial and colluvial fan deposits. Includes Holocene and Pleistocene sediments deposited by intermittent streams and debris flows at the mouths of small drainages. These deposits form fans that onlap pre-Quaternary bedrock of the Lemhi Range and Beaverhead Mountains. Deposits are crudely stratified and very poorly sorted, and they contain pebble- to cobble-sized gravel that is typically clast supported. Matrix is sandy or silty. See additional descriptions of these deposits in Kuntz and others (1994) and Scott (1982).

Qcy—Young alluvial and colluvial fan (Holocene). Pebble to boulder gravel with matrix of silty sand to clayey silt; very poorly sorted; crudely bedded. Subject to flooding; equivalent to unit *Qfc* and *Qfy* of Kuntz and others (1994).

Qco—Old alluvial and colluvial fan (upper Pleistocene). Lithologically similar to unit *Qcy*. Differentiated by higher geomorphic position and greater degree of soil development. Carbonate coats on carbonate clasts are 2 mm or more thick. Unit is older than 100 Ka. Includes unit *Qfo* of Kuntz and others (1994).

Ql—Landslide deposits (Holocene and upper Pleistocene). Blocks of bedrock, pebble to boulder size, in a fine-grained matrix of silty sand to silty clay. Formed by slumps and earthflows. Equivalent to unit *Qcl* of Kuntz and others (1994).

Qt—Talus (Holocene and upper Pleistocene). Angular blocks in a sparse, fine-grained matrix; found at bases of steep slopes. Included within unit *Qcv* by Kuntz and others (1994).

Playa Deposits

The Big Lost River flows northeastward in a well-defined channel across the central INEEL site, but about 1 km north of State Butte in the southwest part of the map area, the channel cannot be distinguished from the lake-floor sediments of Pleistocene Lake Terreton (Spinazola, 1994; Mark and Thackray, 2002). During glacial periods, this area was a lake, but today it is an infiltrative playa system, covered by patches of aeolian sand arranged in northeast-elongated longitudinal dunes, and a clay-sand-bearing playa margin sediment on its northwest and southeast borders south of Howe Point. These playas are normally dry, although they are filled with water in May through early July in years of high spring runoff in the Big Lost River system. Infiltration from these playas is a source for subsurface water of the Snake River aquifer, whose upper surface is several hundred feet below the land surface and which flows southwesterly or opposite the surface flow of Big Lost River.

Qp—Playa-bottom deposits (Holocene and upper Pleistocene). Playa-bottom deposits contain silty to sandy clay; clay content is 18 to 60 percent (Mark, 1999; Mark and Thackray, 2002). Clay types, determined by X-ray diffraction analysis, include kaolinite, illite, smectite, and chlorite, in order of decreasing abundance (Kauffman and Geslin, 1998). These deposits are typically very poorly sorted, probably due to the intermittent influx of eolian sand and its mixing with finer-grained sediments. Sedimentary structures are common and include mud cracks, intraclasts (mud chips), and rare, starved oscillation ripples. Gianniny and others (1997) described biotic remains including copepods, gastropods, ostracodes, oogonia of *Chara* (*Chlorophyta*), and plant fragments. Bright and Davis (1982) reported diatoms and siliceous fresh-water sponge spicules.

Qpm—Playa-margin lunettes (Holocene and upper Pleistocene). Playa-margin deposits were mapped by Kuntz and others (1994) as "lake margin deposits." The deposits have been reinterpreted as lunettes because they ring modern playas, not ancient lakes. Many of these deposits are crescent-shaped dunes that contain sediment deflated from desiccated playas. Playa-margin sediments contain sand-sized grains (clay-sand) composed of aggregates of clay particles deflated by the wind from desiccated playa bottoms. Their grain-size distribution is approximately 60 percent very fine- to fine-sand (clay aggregates) with subordinate amounts of clay and medium- to coarse-grained sand (Mark and Thackray, 2002). They form low (less than 2 m) ridges on the downwind (northeast) side of playas. These playa-margin shorelines show evidence of modification by wave action when the playas were wet. Locally, playa-margin deposits are bioturbated by plants, producing oxidized or calcified root molds. Gastropods and ostracode coquina lenses ring some modern playa bottoms, owing to either mechanical or biological concentration (Gianniny and others, 1997).

Lacustrine Deposits of Lake Terreton

Pleistocene Lake Terreton covered much of the eastern part of the map area (Stearns and others, 1939), including the northern Big Lost Trough and the Mud Lake basin, during five highstands in the last 160,000 years (Gianniny and others, 2002). Mud Lake and the Big Lost River Sinks playa system are modern remnants of Lake Terreton (Spinazola, 1994; Geslin and others, 1999, 2002).

Qlf—Lake Terreton lake-floor deposits (Holocene and upper Pleistocene). Lacustrine sediments in the map area were deposited in Lake Terreton (Stearns and others, 1939). Field relations suggest a complex distribution of depositional facies within the lacustrine environment (Gianniny and others, 1997, 2002). Generally, lake-floor sediments contain more clay (as much as 60 percent) than playa-bottom sediments. In the area between Howe Point and Naval Reactor Facility, lake-floor deposits are cut by minor fluvial channels and associated channel sands and gravels. Lake-floor deposits are overlain locally by overbank deposits and loess. Locally, lake-floor deposits are silty or contain very fine sandy clay. Clays in the lake-floor deposits include kaolinite, illite, and minor chlorite (Kauffman and Geslin, 1998). Subsurface laminated silty clay intervals are 2-10 m thick (Nace and others, 1975; Geslin and others, 1999, 2002; Blair, 2002; Bestland and others, 2002). Ostracodes are typically abundant in lake-floor sediments.

Qlm—Lake Terreton margin deposits (Holocene and upper Pleistocene). A single deposit of lake-margin sediments, originally mapped as eolian sand (Kuntz and others, 1994), is located several km south and east of Howe Point. The lake-margin deposit flanks lake-floor deposits and onlaps alluvial and colluvial fan deposits shed off the southeast flank of the Lemhi Range. This deposit is poorly exposed and has not been studied in detail, but is easily identified on aerial photographs.

Eolian Deposits

Qes—Eolian deposits including minor dunes and loess (Holocene and upper Pleistocene). Deposits include sand sheets, minor longitudinal and barchan dunes, and deposits of loess that mantle other surficial deposits. Dune deposits are dominantly fine to very fine sand but also contain coarse silt to coarse sand. Dune deposits contain subangular to subrounded, compositionally immature sand grains derived chiefly from the distal parts of the Big Lost River system (Nace and others, 1975; Gianniny and others, 1997; Mark and Thackray, 2002). Longitudinal dunes (*Qld*) are the primary form in the map area; other, less systematic sand bodies are composite barchan dunes. Parabolic dunes (lunettes) occur on the downwind side of playas (see description of *Qpm*). Loess deposits are typically silt-dominated and structureless and contain vertical pedogenic fractures. Poorly sorted deposits containing mixtures of dune sand and loess are common in the map area but are not mapped separately.

Qld—Longitudinal dunes (Holocene and upper Pleistocene). Coarse silt to coarse sand, mostly very fine sand. Prominent longitudinal and minor barchan dunes are located south and east of Circular Butte, controlled by strong prevailing winds from the southwest that transported sand northeastward along the axis of the Snake River Plain. Dune sand was derived from alluvial deposits along the Big Lost River near State Butte and to the north.

Agricultural Land

Ag—Agricultural land (Holocene). Agricultural modification of these areas has destroyed surficial geological structures.

Basalt Lava Flows of the Southwestern Area

Qbc_1—Basaltic lava flows of the Crater Butte lava field (middle Pleistocene). Medium to dark gray pahoehoe lava flows of the Crater Butte lava field. Vent area is in sec. 17, T. 3 N., R. 28 E., about 17 km southwest of the southwest corner of the map. Flow fronts are as high as 15 m. Rock is fine to medium grained and contains small (<1.5 mm) phenocrysts of euhedral to subhedral crystals of olivine in a matrix of plagioclase laths, olivine granules, and intergranular granules and blades of clinopyroxene that are all <1 mm. Glomeroporphyritic clots of olivine are common. A recent K-Ar age of 292 ± 58 Ka for the lava field supercedes a previous K-Ar age of 519 ± 52 Ka (M. Lanphere, U.S. Geological Survey, unpub. data, 1998). Normal magnetic polarity.

Qbd_1—Basaltic lava flows of the State Butte lava field (middle Pleistocene). Oxidized red, gray, and black cinders and near-vent, frothy, pahoehoe lava flows of State Butte cinder cone at sec. 16, T. 4 N., R. 30 E. Rock consists of clots of anhedral to subhedral crystals of plagioclase each <3 mm long and small subhedral granules of olivine <1 mm in diameter in a matrix of plagioclase laths, intergranular clinopyroxene, olivine, ubiquitous opaque minerals, and minor brown glass. All components of the matrix are <0.3 mm in longest dimension. K-Ar age is 579 ± 139 Ka (Kuntz and others, 1994). Normal magnetic polarity.

Basalt Lava Flows of the North-Central Area

Qbd_2—Basaltic lava flows of the Antelope Butte lava field (middle Pleistocene, estimated to be 400-780 Ka). Medium to dark gray, dense, porphyritic pahoehoe basalt. Rock has distinctive texture in hand sample that is seen in very few lava flows of the eastern Snake River Plain; abundant single crystals and clots of olivine phenocrysts are much larger than crystals of minerals that form the matrix of the rock. Single olivine crystals are as large as 4 mm in diameter, and clots of olivine crystals are as large as 6 mm. Exposed part of lava field forms a relatively steep-sided cone approximately 3 km in diameter that rises about 50 m above the surrounding, flat terrane. Vent is slot shaped and oriented about N. 80° W. Most of the medial and distal parts of lava field are covered by younger flows and lake-floor sediments (*Qlf*). Most distal flows are 4 km north and east of vent area. In thin section, single crystals and glomeroporphyritic clots of euhedral to subhedral olivine crystals that are 1-6 mm in longest dimension characterize the rock. Randomly oriented plagioclase laths are <1 mm long. Equant, intergranular to subophitic clinopyroxene crystals, plagioclase laths, and olivine granules, all <0.5 mm long, make up the matrix of the rock. Medial and distal parts of field veneered by unmapped eolian sand. Normal magnetic polarity.

Qbd_3—Basaltic lava flows of the Vent 4862 lava field (middle Pleistocene, estimated to be 400-780 Ka). Dark to very dark gray, dense, porphyritic pahoehoe basalt flows. Rock has distinctive texture in hand sample that is seen in very few lava flows of the eastern Snake River Plain; abundant single crystals and clots of olivine phenocrysts are much larger than crystals of other minerals that form the matrix of the rock. Single crystals and glomeroporphyritic clots of euhedral to subhedral olivine crystals that are 1-4 mm in longest dimension characterize the rock. Randomly oriented plagioclase laths are <1 mm long. The matrix of the rock consists of plagioclase laths and olivine granules <0.5 mm long and intergranular to ophitic clinopyroxene crystals, some as long as 2.5 mm. Medial and distal parts of field veneered by unmapped eolian sand. Similar petrographic characteristics and similar paleomagnetic inclinations and declinations for flows of this lava field and of the Antelope Butte lava field (*Qbd_2*) suggest that the fields formed at about the same time, perhaps simultaneously. Normal magnetic polarity.

Qbe_7— Basaltic lava flows of the Montview Butte lava field (lower Pleistocene, estimated to be >780 Ka). Medium to dark gray, coarse-grained, partly porphyritic, pahoehoe basalt. Vent area consists of a steep-sided hill, 20-30 m above the flat surrounding countryside, having a shallow depression at the top that is roughly circular in plan and about 300 m in diameter. Flows beyond 500 m of base of vent area are covered by heavily cultivated fan gravels (*Qao* and *Qay*) and unmapped deposits of loess. In thin section, the rocks are either even grained or porphyritic. In porphyritic rocks, plagioclase laths and mostly equant olivine crystals 2-3 mm long are set in a matrix of plagioclase, olivine, pyroxene, and opaque minerals <0.5 mm long. In even-grained rocks, most crystals are 1-3 mm long. Glomeroporphyritic clots of plagioclase, olivine, and olivine plus plagioclase are common. Reversed magnetic polarity.

Qbe_8— Basaltic lava flows of the Circular Butte lava field (lower Pleistocene). Gray, typically very coarse-grained, partly porphyritic pahoehoe basalt flows. Exposed part of lava field forms a relatively steep-sided cone consisting of rolling, hummocky terrane that is 70-90 m above the flat, surrounding area. Vent is a slot-shaped depression about 250 m by 100 m that is elongated about N. 30º W. Vent surmounts a relatively steep-sided cone that rises about 40 m above surrounding hummocky terrane. The steep-sided cone and the hummocky character of the lava field suggest that Circular Butte flows erupted with relatively high viscosity resulting from the large volume of coarse plagioclase crystals in lava. Most of the medial and distal parts of the lava field are covered by younger flows, lake-floor sediments (*Qlf*), loess, and eolian sand; because of the discontinuous nature of these units, they are not shown by a separate pattern. The most distinctive feature of Circular Butte rocks in thin section is the large size and textural character of plagioclase crystals. Plagioclase crystals are 2-15 mm long; typically three to ten crystals are attached to form epitaxial glomeroporphyritic clots. Olivine crystals are subhedral and 0.5-1.5 mm in diameter. Glomeroporphyritic clots containing as many as ten olivine crystals are common. Clinopyroxene crystals are typically <0.5 mm long and intergranular to subophitic. See Casper (1999) for additional information. K-Ar age is 1.094 ± 86 Ma. Reversed magnetic polarity.

Lava Flows of the Lava Ridge Area

Qbe_1—Basaltic lava flows (lower Pleistocene). Medium to dark gray or black, mostly porphyritic, pahoehoe basalt lava flows and minor amounts of weakly oxidized, reddish gray to reddish black, near-vent cinder and scoria deposits. Poorly exposed vent near spot elevation 5,450 feet in sec. 35, T. 8 N., R. 30 E., is represented by a shallow depression <40 m in diameter that is surrounded by scattered deposits of cinders and scoria. Vent area is onlapped on west by pebble and gravel alluvial and colluvial deposits (*Qco*, *Qcy*) west of Birch Creek. Margins of flows are onlapped and locally covered by pebble and gravel alluvial and colluvial deposits of alluvial fans, by gravel and sand of alluvial deposits along Birch Creek (*Qay*, *Qes*), and locally by thin, unmapped deposits of loess. Rock has dense matrix and contains abundant small plagioclase crystals <3 mm long. Olivine is present as moderately abundant single crystals <2 mm long and glomeroporphyritic clots <4 mm long. In thin section, rock contains glomeroporphyritic clots of plagioclase and plagioclase plus olivine that are <3 mm in diameter. All thin sections contain a few cross- and X-shaped, intergrown pairs of plagioclase crystals. Plagioclase crystals are typically stubby, having length to width ratios less than 3:1. Olivine crystals are equant, subhedral, and <1.5 mm. Clinopyroxene is absent in samples from near the vent but occurs as blade- and wedge-shaped crystals near edges of flow. Petrographically similar to flows of *Qbe*$_4$. K-Ar age is 807 ± 33 Ka. Reversed magnetic polarity.

Qbe$_2$—Basaltic lava flows and dikes (lower Pleistocene, estimated to be >780 Ka). Medium to dark gray, medium to coarse, porphyritic pahoehoe basalt flows. Vent is a 0.5-1 m wide, about 100 m long dike oriented N. 50º W. about 100-200 m southeast of spot elevation 5,305 feet. Flanks of dike are surrounded by reddish cinders. Flow fronts that surround the lava lake southeast of vent area are steep. Surface and margins of flows are locally covered by thin, unmapped deposits of loess. Rock is distinctive in thin section, containing olivine phenocrysts as long as 7 mm in a matrix of plagioclase, olivine, and clinopyroxene crystals that are <0.5 mm long. Glomeroporphyritic clots of olivine are common; large olivine crystals are partly skeletal. Reversed magnetic polarity.

Qbe$_3$—Basaltic lava flows of Richard Butte (lower Pleistocene). Medium to dark gray, extremely coarse, porphyritic pahoehoe basalt flows and near-vent tephra deposits. Vent area at Richard Butte is a roughly circular depression about 350 m in diameter, the surface of which is covered by mostly dark gray bombs and reddish black tephra. Flows are distinctly coarse in hand specimen, containing abundant large (3-7 mm long) crystals of plagioclase. Thin sections of rock show slender plagioclase crystals having length to width ratios >5:1. Glomeroporphyritic clots of plagioclase crystals are common and typical of the rock. Olivine crystals are subhedral and typically <1 mm long. Clinopyroxene is absent to intergranular. Petrographically similar to flows of *Qbe*$_8$. Reversed magnetic polarity.

Qbe$_4$—Basaltic lava flows (lower Pleistocene, estimated to be >780 Ka). Light to medium gray, medium coarse, porphyritic to glomeroporphyritic, pahoehoe basalt flows. Vent area is not exposed. Western part of unit is onlapped by pebble and gravel deposits (*Qco*) of alluvial fans west of Birch Creek, by gravel and sand of alluvial deposits (*Qay*) along Birch Creek, and locally by thin, unmapped deposits of loess. Rock is distinctly medium to coarse grained, containing plagioclase laths <4 mm long. Glomeroporphyritic clots <5 mm long of plagioclase and plagioclase + olivine are common. Olivine crystals are equant, subhedral, and <1.5 mm long. Clinopyroxene is absent in samples from western part of unit but occurs as blade- and wedge-shaped crystals near edges of flow. Petrographically similar to flows of *Qbe*$_1$. Reversed magnetic polarity.

Qbe$_5$—Basaltic lava flows (lower Pleistocene, estimated to be >780 Ka). Medium gray, even-grained, felty pahoehoe basalt lava flows. Vent area is not exposed but presumably lies just north, northwest, or west of spot elevation 5,044 feet. Surface and margins of flows are mostly covered by loess. Rock has distinctive felty texture in thin section, consisting of a mat of randomly oriented plagioclase crystals typically <2 mm long and rare to moderately abundant single crystals (<5 mm long) or glomeroporphyritic clots (<8 mm long) of subhedral to euhedral crystals of olivine. Abundant clinopyroxene crystals range from granules <0.5 mm long to anhedral, subophitic crystals <2 mm long. K-Ar age is 939 ± 154 Ka. Reversed magnetic polarity.

Qbe$_6$—Basaltic lava flows (lower Pleistocene, estimated to be >780 Ka). Dark gray, fine- to medium-grained, partly felty, porphyritic basalt lava flows. Vent area is a deeply loess-filled, rectangular depression 800 m by 500 m. The shape of the vent and the absence of shelly pahoehoe and reddish cinders suggest that the vent probably represents a former lava lake. Surface of flow is mostly covered by loess. Western margins of flow are onlapped by gravels and sand (*Qco*) and loess. Most samples of unit show a distinctive porphyritic texture in which glomeroporphyritic clots of randomly oriented plagioclase laths 0.5-2 mm long and round, anhedral to subhedral crystals of olivine 0.2-0.6 mm in diameter are set in a matrix of plagioclase, olivine, and opaque minerals that are all <0.2 mm long. Clinopyroxene crystals <0.1 mm long occur only as part of the matrix. Reversed magnetic polarity.

Qbe$_9$—Basaltic lava flows (lower Pleistocene, estimated to be >780 Ka). Medium gray, equigranular, pahoehoe basalt lava flows. Vent area is not exposed but presumably lies 1-3 km west of present outcrop area, where it is covered by fan deposits (*Qco*). Flows of unit are poorly exposed owing to extensive cover by surficial deposits: western part of unit is onlapped by pebble and gravel deposits (*Qco*) of alluvial fans west of Birch Creek; margins of flows are onlapped and locally covered by pebble and gravel deposits of alluvial fans (*Qco*), by gravel and sand of alluvial deposits along Birch Creek (*Qay*), and locally by thin, unmapped deposits of loess. The rock is distinguished by equigranular texture; it contains plagioclase and olivine crystals that are typically <1 mm long. Clinopyroxene is typically <1 mm long and intergranular to subophitic. Magnetic polarity is not determined; thus age relationships with adjacent lava fields and other lava fields on Lava Ridge cannot be determined.

QTb—Basalt lava flow on east side of Howe Point Ridge (Pleistocene and Pliocene?). Dark gray, dense to slightly vesicular, aphyric to plagioclase-phyric basalt (Kuntz and others, 1994). Limited to two exposures on eastern side of the southern Lemhi Range. Undetermined magnetic polarity

(McBroome, 1981). Thickness greater than 20 m.

Basalt Lava Flows of the Southeastern TAN Area

Qbc$_2$—Basaltic lava flows of the Microwave Butte lava field (middle Pleistocene). Medium to dark gray, black pahoehoe flows from vent in sec. 28, T. 3 N., R. 33 E., about 8 km south-southwest of southeast corner of this map. Vent area is known informally as Microwave Butte. Flows are hummocky and have local relief of 5-10 m. Rock is fine to medium grained. Felty plagioclase crystals are <1 mm long and subhedral to euhedral crystals of olivine are <2 mm in diameter. Clinopyroxene is present only as tiny skeletal blades <0.3 mm long in the matrix or as part of a nearly opaque, intersertal glassy matrix. Age interpreted to be <300 Ka based on geologic and paleomagnetic correlation with K-Ar dated flows in cores (see Kuntz and others, 1994). Normal magnetic polarity.

Qbc$_3$—Basaltic cinder deposits and lava flows of the Teat Butte lava field (middle Pleistocene, estimated to be 200-400 Ka). Oxidized red, dark gray, and black cinder deposits and near-vent, frothy, shelly pahoehoe flows from vent in sec. 15, T. 5 N., R. 32 E., known informally as Teat Butte. Vent area consists of cinder deposits and spatter ramparts elongated about N. 50º W. Cinders and frothy pahoehoe flows are typically porphyritic, having phenocrysts of plagioclase laths as long as 2 mm and subhedral to euhedral, equant olivine crystals as wide as 1.5 mm. The phenocrysts are set in a matrix of crystals, all of which are <0.5 mm in longest dimension. Clinopyroxene is confined to the matrix as intergranular to subophitic crystals. Cinder deposits and spatter ramparts rise as high as 25 m on the flanks of a 0.5 km-long, northwest-southeast elongated depression that represents the location of an eruptive fissure. An approximately 0.5- to 1-km-wide moat around the vent area is formed by steep flow fronts.

Qbc$_4$—Basaltic lava flows of the Vent 4853 lava field (middle Pleistocene, estimated to be 200-400 Ka). Gray to dark gray and black pahoehoe lava flows, near-vent cinder deposits, and shelly pahoehoe flows from unnamed vent in sec. 23, T. 5 N., R. 32 E. Flows are locally covered by a thin veneer of unmapped eolian sand. Largest crystals in rock are phenocrysts of plagioclase as long as 2.5 mm and euhedral to subhedral olivine as much as 1.8 mm in diameter. Plagioclase, olivine clinopyroxene, and opaque minerals in the matrix are mostly <1.2 mm long. Clinopyroxene is intergranular to subophitic. Glomeroporphyritic clots of olivine and olivine plus plagioclase are common. Normal magnetic polarity.

Qbc$_5$—Basaltic lava flows of the Vent 5171 lava field (middle Pleistocene, estimated to be 200-400 Ka). Medium gray to dark gray and black pahoehoe flows, near-vent cinder deposits, and shelly- pahoehoe flows from aligned, unnamed vents in sec. 20, T. 4 N., R. 33 E. Flow fronts at northwest margin of unit are steep and as high as 12 m. Rock is porphyritic, having plagioclase and olivine phenocrysts 1-2 mm in longest dimension in an intergranular to intersertal matrix in which plagioclase, olivine, clinopyroxene, and opaque minerals or patches of glass are <0.5 mm long. Glomeroporphyritic clots of plagioclase, olivine, and olivine plus plagioclase are common. Petrographically similar to *Qbc$_6$*. Normal magnetic polarity.

Qbc$_6$—Basaltic lava flows of the Vent 5313 lava field (middle Pleistocene, estimated to be 200-400 Ka). Medium to dark gray and black pahoehoe flows, near-vent cinder deposits, and shelly pahoehoe flows from unnamed vent in sec. 35, T. 4 N., R. 33 E., in southeast corner of this map. Rock is porphyritic, having plagioclase and olivine phenocrysts 1-2 mm in longest dimension in an intergranular to intersertal matrix in which plagioclase, olivine, clinopyroxene, and opaque minerals or patches of glass are <0.5 mm long. Glomeroporphyritic clots of plagioclase, olivine, and olivine plus plagioclase are common. Also common are starburst and cross arrangements of plagioclase phenocrysts. Normal magnetic polarity.

Qbc7—Basaltic lava flows (middle Pleistocene, estimated to be 200-400 Ka). Gray to dark gray and black pahoehoe lava flows. Vent area unknown; probably distal flows of Vent 5305 (*Qbc$_8$*) lava field. Largest crystals in rock are medium-sized phenocrysts of plagioclase 1-3 mm long and relatively small crystals of olivine that are <1.5 mm in diameter. The matrix of the rock consists of plagioclase laths <0.5 mm long, granules of olivine <0.3 mm, and intergranular blades and laths of clinopyroxene <0.5 mm. Normal magnetic polarity.

Qbc$_8$—Basaltic lava flows of the Vent 5305 lava field (middle Pleistocene, estimated to be 200-400 Ka). Gray to dark gray and black pahoehoe lava flows. Vent area consists of a shallow, slot-shaped depression, about 200 m long and 20 m wide, which is oriented N. 35º W. Largest crystals in rock are medium-sized phenocrysts of plagioclase 1-3 mm long and relatively small crystals of olivine that are <1.5 mm in diameter. The matrix of the rock consists of plagioclase laths <0.5 mm long, granules of olivine <0.3 mm, and intergranular blades and laths of clinopyroxene <0.5 mm. Normal magnetic polarity.

Qbc$_9$—Basaltic lava flows of the Vent 4981 lava field (middle Pleistocene, estimated to be 200-400 Ka). Gray to dark gray and black pahoehoe lava flows. Vent area is an approximately circular depression about 200 m in diameter. Largest crystals in rock are medium-sized phenocrysts of plagioclase 1-3 mm long and relatively small crystals of olivine that are <1.5 mm diameter. The matrix of the rock consists of plagioclase laths <0.5 mm long, granules of olivine <0.3 mm, and intergranular blades and laths of clinopyroxene <0.5 mm. Locally, rock is porphyritic, having plagioclase and olivine phenocrysts 1-2 mm in longest dimension in an intergranular to intersertal matrix in which plagioclase, olivine, clinopyroxene, and opaque minerals or patches of glass are <0.5 mm long. Normal magnetic polarity.

PRE-QUATERNARY UNITS

Tertiary units are exposed on Howe Point at the southern tip of the Lemhi Range and in the southern Beaverhead Mountains. The map contains new mapping of the Howe Point area and incorporates new Ar/Ar dates by M.H. Anders and others (unpub. data).

Tbc—Tuff of Blue Creek and underlying ash units (Miocene, 6.19 ± 0.01 Ma, M.H. Anders and others, unpub. data). Light gray, light bluish gray, black, lavender, dark red, and pink, phenocryst-poor (<2 percent total phenocrysts), glassy to devitrified, spherulitic, lithophysal, densely welded, rhyolitic ignimbrite. Phenocrysts average 1 percent and include plagioclase; minor amounts of sanidine, quartz, pyroxene, magnetite, and zircon; and trace amounts of biotite. Base of unit is generally thin, black, phenocryst-poor vitrophyre, which grades upward into a perlitic to spherulitic vitrophyre. The perlitic-spherulitic vitrophyre is overlain by a massive to platy, dark red devitrified zone that grades upward into a lavender to light bluish gray devitrified zone. Locally, lithophysal cavities are present near top of devitrified zone. The unit is capped by distinctive vitrophyre containing red to pink fiamme and nonwelded vitric ash. Thickness is 0-180 m. Below tuff of Blue Creek are a series of ash units that consist of a basal tan, locally laminated and crossbedded, nonwelded ash, which grades upward into a welded ash- and pumice-fall deposit. Welded ash-fall deposit contains abundant orange pumice fragments and subordinate amounts of lithic clasts in a matrix of black shards. Welded ash-fall deposit is cogenetic with the Walcott Tuff. Thickness of welded ash-fall deposit ranges from approximately 0.5 m at southern tip of Lemhi Range to zero farther north. Total thickness of cogenetic ash deposit is 0.2 m. Normal magnetic polarity was determined by alternating field demagnetization (Morgan, 1988).

This unit is similar in texture, composition, age, and paleomagnetic direction to the Walcott Tuff, whose type section is along the southern margin of the Snake River Plain. Kuntz and others (1994) interpreted the tuff of Blue Creek and the Walcott Tuff to be identical and used the term Walcott Tuff everywhere in place of tuff of Blue Creek. However, in a study of subsurface rhyolite recovered from core hole WO-2 on the eastern Snake River Plain, M.H. Anders and others (unpub. data) identified an unconformity between two rhyolite units whose age and paleomagnetic direction were similar. They interpreted the lower unit as Walcott Tuff and the upper unit as tuff of Blue Creek. This unconformity may be evident at Howe Point in the section described by Hackett and Morgan (1988), below the tuff of Blue Creek in the “unnamed ash” unit. The designation tuff of Blue Creek is retained for this map, but the unit may locally contain rocks correlative with the Walcott Tuff.

Tb—Tuff of Blacktail Creek (Miocene, 6.57 ± 0.01 Ma, M.H. Anders and others, unpub. data). Medium to light gray, brown, and black, glassy to devitrified, locally lithophysal, densely welded rhyolitic ignimbrite. Phenocryst content ranges from 15-20 percent at the base to <7 percent at the top; phenocrysts include plagioclase, sanidine, quartz, augite, and zircon. Base of ignimbrite is a tan to dark brown, grading upward to black, densely welded vitrophyre; locally, the base contains abundant lithic fragments. Basal vitrophyre grades upward into a dark gray spherulitic one, which is overlain by a medium gray spherulitic zone grading upward to a light gray, densely welded massive devitrified zone. Upper part of devitrified zone is light gray, contains lithophysal cavities, constitutes most of the ignimbrite, and is capped by a 15- to 30-cm-thick, medium gray vitrophyre. Normal magnetic polarity was determined by alternating field demagnetization (Morgan, 1988). Thickness is 20-60 m and averages 30 m.

Tlrs—Tuff of Lost River Sinks (Miocene, (8.75 ± 0.16 Ma, M.H. Anders and others, unpub. data). Simple cooling unit of welded tuff that consists of multiple layers of dense, devitrified lithophysal rhyolitic ignimbrite. Unit exposed in single exposure along Idaho State Highway 33 at Howe Point at the southern tip of the Lemhi Range. Normal magnetic polarity (M.H. Anders, unpub. data). Thickness 0-5 m.

Tbs—Unnamed basaltic lava flows (Miocene). Dense to vesicular aphyric to slightly plagioclase-phyric basaltic lava flows. Basal parts of flows are mottled, dark brown weathering, dense basalt containing rare, large (3 mm long) crystals of plagioclase and very small crystals of olivine and pyroxene. Upper red-weathering parts of lava flows contain vesicles filled by calcium carbonate. Limited exposures in southern Lemhi Range about 3 km north-northwest of Howe

Point. Thickness is 0-30 m.

Tkc—Tuff of Kyle Canyon (Miocene, 9.17 ± 0.01 Ma, M.H. Anders and others, unpub. data). Dark red to brownish purple, crystal-poor, densely welded, platy, rhyolitic ignimbrite. Phenocryst content is less than 5 percent and is composed of subhedral 2 mm long sanidine, 0.5 mm wide by 2 mm long plagioclase, and small (<1 mm long) milky quartz crystals. Pumice is rare, uncompacted, and about 1 mm in size. Upper devitrified zone has platy partings showing vapor-phase mineral crystallization and flowage features. Thin (1-5 cm thick), incipiently to moderately welded ash-fall(?) poor, internally stratified, well sorted, and slightly pumiceous. Limited exposures in southern Lemhi Range about 4-6 km north of Howe Point. Normal magnetic polarity (M.H. Anders, unpub. data). Thickness is 5-50 m and averages about 30 m.

Ta—Arbon Valley Tuff Member of Starlight Formation (Miocene, 10.22 ± 0.06 Ma, Kellogg and others, 1994; 10.20 ± 0.01 Ma, M.H. Anders and others, unpub. data). Pale yellow to light gray phenocryst-rich, bipyramidal quartz- and biotite-bearing ignimbrite named by Kellogg and others (1994). At northern limit of exposure along Howe Point, the base of unit is a crystal-rich ground surge deposit overlain by crystalline, laminated unwelded tuff. Main part of unit is welded, glassy, gray tuff (20 m), with 2-4 mm long euhedral quartz, biotite and uncommon 0.5-1 cm long pumice fragments. A devitrified, pumice-rich zone caps the unit. Unit forms low cliffs topped by rounded ledges. At southern limit of exposure along the Howe Point ridge, the Arbon Valley Tuff Member contains pumice-rich, lithic-bearing fallout tuff that forms rounded ledges and wind-eroded hollows. Magnetic polarity has not been determined. M.H. Anders and others (unpub. data) produced fifteen high-precision Ar/Ar dates for the Arbon Valley Tuff Member regionally, which fall into two clear groups, six with a weighted average of 10.09 ± 0.02 Ma and nine with a weighted average of 10.27 ± 0.02 Ma. This suggests two distinct eruptions. Thickness 0-60 m and averages 20 m.

Tc—Unnamed conglomerate (Miocene). Tan, matrix supported, poorly sorted, uncompacted pebble conglomerate, sparsely exposed. Bedding is not visible. Clasts include volcanic lithic fragments, quartzite, limestone, chert, and siltstone. Clasts are subangular to subrounded and range from 3 mm to 3 cm in size. The matrix is coarse to very coarse, lime-cemented sandstone. Consists of two stratigraphic units of conglomerate: the lower one is about 18 m thick, below unit *Ttl*; the upper one is 3-5 m thick and matrix supported.

Ttl—Unnamed tuff and limestone (Miocene,16.02 ± 0.15 Ma, M.H. Anders and others, unpub. data). Intercalated white algal lacustrine limestone, tuffaceous limestone containing rhizoliths, reworked volcanic sandstones containing a paleosol with a Ck/Bk horizon, and unbedded, massive limestone containing bioherms and rare gastropod fossils. Two-thirds of the way up through the unit is a 15-cm-thick marker bed of gray-white, laminated, vitric, air-fall volcanic ash dated at 16.02 ± 0.15 Ma. This marker ash mantles a 1-m-thick bed of massive lacustrine limestone containing well-developed, 1 m by 0.5 m bioherms. The upper part of *Ttl* is fine to medium grained, light yellow-brown, noncalcareous cross-bedded sandstone intercalated with sandy limestone and lacustrine limestone. Unit thickness about 5 km north of Howe Point is about 36 m.

PALEOZOIC ROCKS

PMsc—Snaky Canyon Formation (Lower Permian to Upper Mississippian). Interbedded limestone, dolostone, and minor sandstone. Limestone and dolostone are medium gray to light gray, fine to coarse grained, sandy, variably cherty, and fossiliferous (brachiopods, corals, mollusks, trilobites, calcareous microfossils). Sandstone is quartzose, calcareous, medium to light gray, very fine grained, medium bedded, and locally fossiliferous (calcareous microfossils and brachiopods); weathers pale brown to moderate yellowish brown; forms low ledges. Crops out at the base of exposures at Howe Point at the south end of the Lemhi Range, and as isolated knobs projecting from Miocene volcanic and sedimentary rocks along the southeast side of the Lemhi Range.

TERTIARY, PALEOZOIC, AND LATE PROTEROZOIC ROCKS

TPzZr—Pre-Quaternary rocks of the Lemhi Range and Beaverhead Mountains (Tertiary, lower Paleozoic, and Late Proterozoic). Located along the western margin of the map. Contains mainly Lower Permian to Upper Mississippian mixed siliciclastic-carbonate Snaky Canyon Formation and underlying Paleozoic marine carbonate strata. At the southern end of the Beaverhead Mountains (Reno Point) are Tertiary volcanic rocks and lower Paleozoic and Late Proterozoic strata. See Kuntz and others (1994) for

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