

EXHIBIT

104

SILICIC VOLCANIC ROCKS AND STRUCTURE OF
THE WESTERN MOUNT BENNETT HILLS AND ADJACENT
SNAKE RIVER PLAIN, IDAHO

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INTRODUCTION

The western Mount Bennett Hills meet the Snake River Plain at the intersection of the northwestern trending western plain with the northeastern trend of the eastern plain along the "track of the Yellowstone Hot Spot" (Fig. 28). These hills contain a greater than 1 km thick sequence of Miocene silicic volcanic rocks, perhaps the thickest along the margins of the Snake River Plain. This sequence is composed of many layers of flow-banded rhyolite. The widespread nature of each mappable unit suggests that the rhyolites were originally emplaced as hot ash flows that welded, remelted, and ultimately flowed as viscous lavas. Along U.S. Highway 20 are exposures of the controversial rhyolite flows and a rare occurrence of pyroclastic material within the sequence. This occurrence provides an excellent place to address the controversy regarding origin and nomenclature of these rocks.

Study of this area was initiated in support of the "hot-dry rock (HDR) geothermal energy project" of Los Alamos National Laboratory. This immediate area had been selected as one with potential for an experiment involving drilling and hydraulic fracturing of the rhyolite or granite in deep wells, and circulating fluids to extract the heat energy of the rock (Arney et al., 1982; Arney, 1982). Selection of this area was based on a 1973 petroleum exploration well 10 km south of the margin of the plain that encountered temperatures of 195°C at a depth of 2950m (9,676 ft) and rock types similar to that at the prototype experiment near the edge of the Valles Caldera at Los Alamos, New Mexico. Subsequent changes in government funding and energy prices curtailed other HDR experiments, except for the project at Los Alamos.

Geologic mapping was done by Wood and Gardner (1984) to identify structure and to determine total stratigraphic thickness of the silicic volcanic rocks deposited upon granite of the Idaho batholith. This sequence of lithoidal and glassy rhyolite

contains no sedimentary or basalt interbeds. It is difficult to develop a field stratigraphy in such similar appearing rocks. Features used to distinguish mappable units are: (a) feldspar phenocryst size and abundance, (b) recognition of a typical vertical zonation of rhyolite lithology and flow structures within each flowage unit, (c) magnetic polarity of the rocks determined with a field fluxgate magnetometer, and (d) aerial and vertical stratigraphic distribution and typical thickness of a unit.

Rhyolites of this area are a part of the Idavada group, a stratigraphic name that includes many of the later Neogene silicic volcanic rocks of the western Snake River Plain (Malde and Powers, 1962; Malde, et al. 1963; and Armstrong, et al., 1980). Structure and stratigraphy of the area is illustrated in Figures 29, 30 and 31. Principal subdivisions of the Idavada Group in this area are the rhyolites of the Danskin Mountains, a younger sequence, that onlaps the rhyolites of the Bennett Mountain fault block. The older Bennett Mountain sequence contains three magnetic polarity reversals, whereas the younger Danskin Mountains sequence is entirely of normal polarity. Several units thin to the north suggesting that the eruptive vents lay to the south either within or across the present plain.

Many rhyolite layers of the sequence are mappable over a distance of at least 15 km. Because they are widespread, most of the rhyolite layers are believed to be densely welded ash-flow tuffs even though most are dense, glassy and lithoidal rhyolite without megascopic features of a pyroclastic rock. If a unit is emplaced as an ash-flow, but is remelted and flows as a lava, how should it be named? Wood and Gardner (1984) chose to call map units in this area rhyolite flows rather than tuffs, since they have features most characteristic of rhyolite lavas. Wolff and Wright (1981), describe rheomorphism of welded tuffs, but welded tuffs they describe have abundant remnant pyroclastic features. While many of the rhyolites in

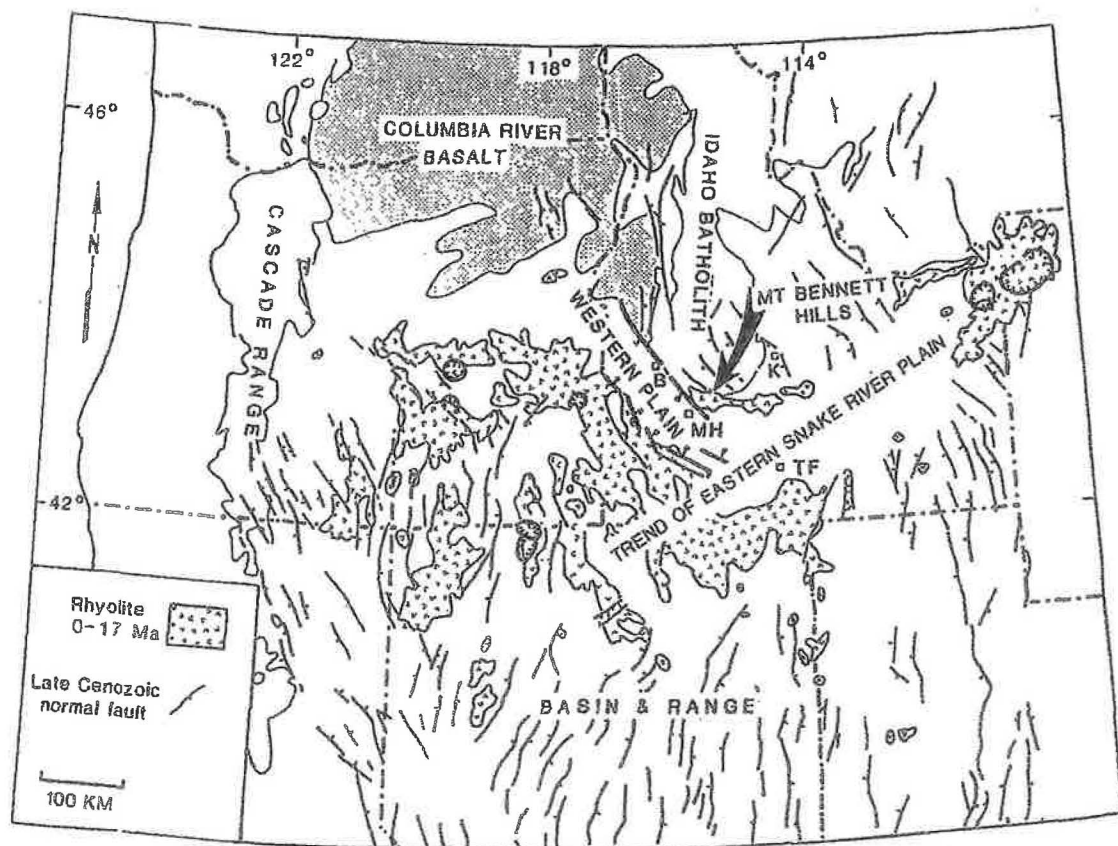


FIGURE 28. Map of the northern basin and range province showing rhyolite fields and caldera systems younger than 17 Ma (after Stewart and Carlson, 1978), late Cenozoic normal faults, and the intersecting trends of the western Snake River Plain graben with the eastern plain "hot-spot track" (modified from Ekren et al., 1984). Panorama of the intersecting trend will be viewed from the microwave-relay hill (Fig. 7). A = Albion Mountains, K = Ketchum, B = Boise, MH = Mountain Home, J = Jarbidge Mountains, TF = Twin Falls.

the western Mount Bennett Hills may be rheomorphic tuffs, the pyroclastic features have been obliterated during welding and flowage. Controversial features and origins of similar rocks on the south side of the Snake River Plain were first described by Ekren et al. (1984) and Bonnicksen and Kauffman (1987). Some insight into the nature and origin of these unusual rhyolite rocks can be gained from study of features seen in roadcuts east of Tollgate Cafe (First Stop), where pyroclastic rock is intimately associated with dense rhyolite flow rock.

STOP AT MILEPOST 107.5, EVIDENCE FOR ASH-FLOW ORIGIN OF THE RHYOLITE AT TOLLGATE

At the Tollgate Cafe locality, one flow unit that shows features of both rhyolite ash-flow tuffs and rhyolite lava is exposed

in the roadcut (Figs. 29, 32, 33). This material is not typical of the rhyolite of the area, but the variety of colorful rhyolite lithologies is worth collecting, and the relationships should provoke discussion on the origin and processes that formed this material.

Orange breccia containing fiamme was originally noticed as float rock near the top of a thick map unit called the rhyolite of Dive Creek (Fig. 30). This roadcut is the only locality where the breccia is well exposed. Its distribution in the immediate area is shown in Figure 32 as a discontinuous unit up to 80 feet (25-m) thick, always associated with vitrophyre. It lies between thick units of massive flow-banded lithoidal rhyolite that dip about 8° northeast. Within the unit are zones of breccias and welded material composed of reddish orange matrix of ash and phenocrysts

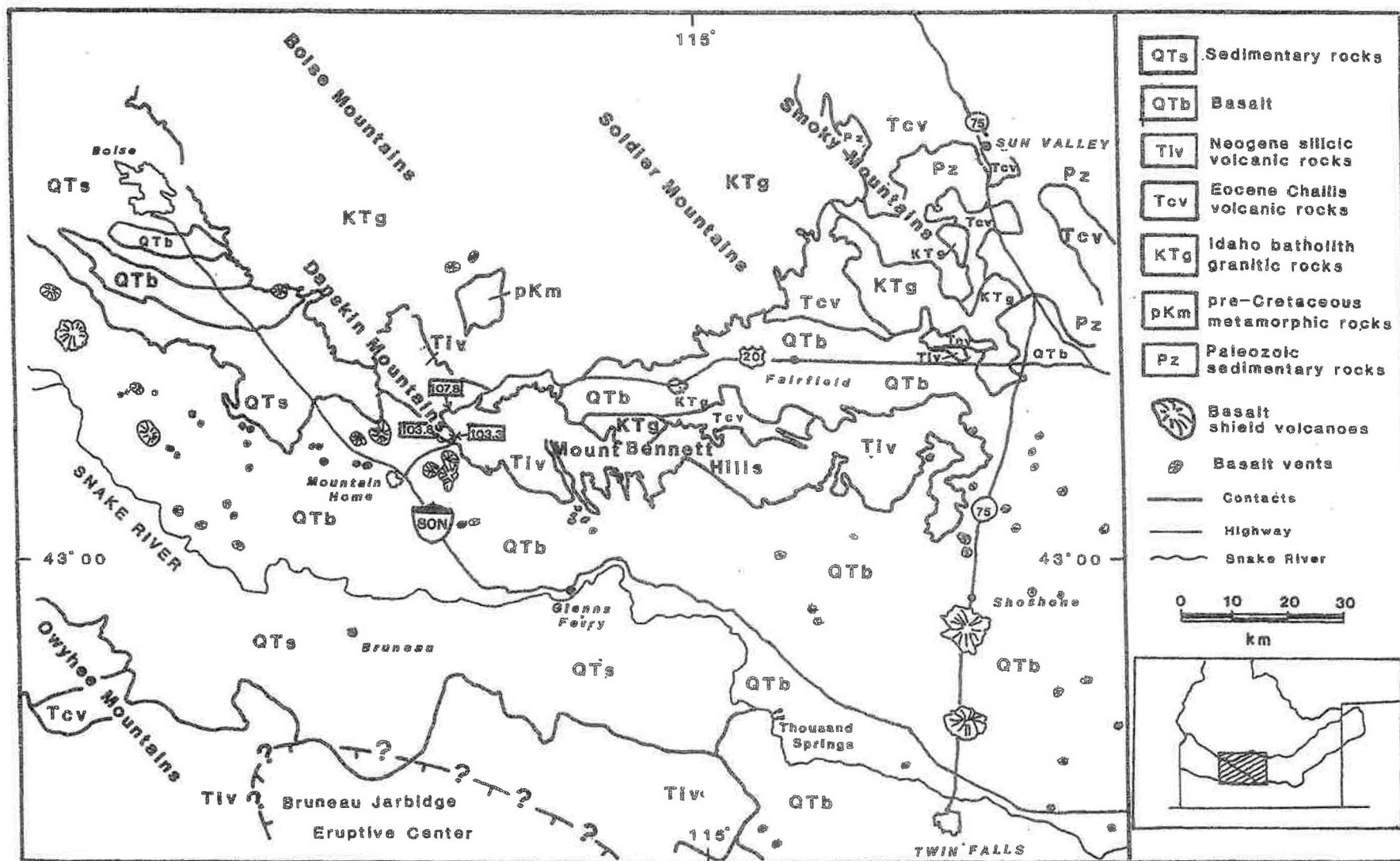


FIGURE 29. Geologic map of the Mount Bennett Hills, Magic Reservoir area showing localities described in text. (Modified from Bond, 1978).

EPOCH GROUP	LITHOLOGIC UNIT	K-AR DATES (Ma)
Pliocene & Pleistocene	Bruneau Fm. & Snake River Group	1.0-2.0
	olivine basalt & scoria fan deposits	
	Idaho Group	
	lacustrine & fluvial sediment	
Miocene	Basalt of upper Cold Springs Creek & High Springs	
	Palagonitic and rhyolitic ashly tuff	
	DANSKIN MTNS.	
	Rhyolite of High Springs	
	Rhyolite of Dive Creek	
	Rhyolite of Rattlesnake Springs	
	Rhyolite of Frenchman Springs	~9.0
	Idavada Group	
	BENNETT MTN BLOCK	
	Henley rhyolite	
Eocene	Rhyolite of Bennett Mountain	
	Rhyolite of Windy Gap	11.0
	Unnamed reversed rhyolite	
	Unnamed normal rhyolite	
Eocene & Eocene	Challis Volcanic Group	40-51
	rhyolite tuff and intermediate flow rocks	
Cretaceous & Eocene	Idaho batholith	42-81
	granitic rocks	

FIGURE 30. Generalized stratigraphy of the western Mount Bennett Hills and the eastern Danskin Mountains from Wood and Gardner (1984).

surrounding angular pieces of dense black vitrophyre. Breccias grade into thin zones containing fiamme of black vitrophyre in an orange matrix, and these fiamme zones grade into massive black vitrophyre. This relationship is best seen in the roadcut at point "A" shown on Figure 33. It appears that all stages of welding are represented at this locality. The variable dips of contacts between zones and steep inclination of banding within the dense vitrophyre mass suggest that the material was welding and undergoing flow deformation at the same time.

Most of the unwelded breccia is composed of orange ash and angular black vitrophyre fragments. Pumice clasts are not abundant except at point "b" of (Figs. 33, 34). Fiamme could have formed by flattening of hot vitrophyre fragments (Gibson and Tazieff, 1967) as well as from the collapse of molten pumice as is usually advocated.

Low on the northeast side is fine clayey brown ash and white ash. Some of the white ash is bedded. Steep contacts and discontinuous nature of this fine material suggests it may unconformably underlie the breccia and vitrophyre flow.

This locality shows that dense black flow-banded vitrophyre can be derived from pyroclastic material. It raises the possibility that much of the glassy rhyolite in this area is of pyroclastic origin. Much of the lithoidal rhyolite may have originated in a similar manner and then devitrified to a stoney appearing rock. Folded flowbanding in the dense rhyolite indicates that it flowed as a viscous lava.

STOP AT MICROWAVE-RELAY HILL:

MILEPOST 103.8,
VIEWPOINT OF JUNCTURE OF EASTERN AND WESTERN
SNAKE RIVER PLAIN

The top of the hill affords a panoramic view of the intersection of the eastern and western trends of the Snake River Plain (Fig. 35). The hilly northern border of the plain is associated with northwest-southeast-trending normal faults of the western plain graben structure which is here about 60 km wide. Faulting of the rhyolite shows that foundering of the western-plain graben continued after cessation of rhyolite volcanism about 9 Ma. The top of the rhyolite section has been downfaulted and downwarped at least 1.4 km along the NE margin (Fig. 31 and Wood and Burnham, 1987) and at least 1 km along the SW margin of the western plain (Ekren et al., 1981). Beyond Teapot Dome Hill (Fig. 35) to the southeast is the apparent end of this graben structure.

Near this intersection of the eastern and western plain, fault blocks have an unusual 15° tilt to the north and northeast away from the plain. East of here, faults mapped by Malde et al. (1963) have a west-northwest orientation, and the upper volcanic section along the margin dips to the south toward the plain. Marginal faults northwest of here have not been studied, but in the Boise area, 50 km west of here, the volcanic section is tilted SW toward the plain. Only in this area is the

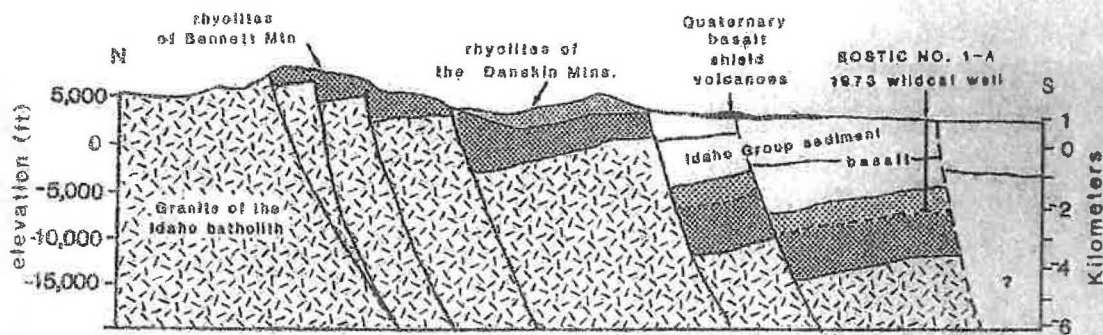


FIGURE 31. Structure section of the northern margin of the western Snake River Plain looking east from the microwave-relay hill. Idavada rhyolite rocks of Miocene age lie upon granitic rocks of the Idaho batholith. Sedimentary rocks (no pattern) of the Neogene Idaho Group lie upon Idavada rhyolites. Section is based on mapping by Wood and Gardner (1984), deep Schlumberger resistivity soundings reported in Whitehead (1986), and study of the Griffith-Bostic A-1 well by Arney (1982).

dip anomalous and inconsistent with the downwarped structure of the plain.

Boundary faults on the NE margin of the western plain are parallel to a set of NW-SE trending normal faults that have sliced the southern Idaho batholith into blocks about 20 km wide during late Cenozoic time (Att, 1986; Fig. 28). Why the western graben is so much wider than other fault blocks of the system and vertical offset so much greater is unknown.

Features Seen on the Southwestern Skyline

The high mountains to the southwest are the Owyhee Range composed primarily of Mesozoic batholithic rocks similar to the Idaho Batholith. Minor lithologies are a small pendant of pre-Cretaceous calc-silicate metamorphic rocks, patches of Eocene Challis and Oligocene (26 to 30 Ma) calc-alkaline volcanic rocks (Ekren et al., 1981; Norman et al., 1985), and a carapace of Miocene Idavada silicic volcanic rocks 9 to 15 Ma.

The greatest physiographic relief (1 km) of mountains marginal to the plain is where granitic rocks of the batholith are exposed, suggesting that the western plain structure has greatest structural relief where it breaks the batholith. Terrain underlain by granite is identified by a low Bouguer gravity anomaly (-150 mgal) indicating deep roots of low density granitic rocks (Eaton, et al., 1978). Although the plain is a deep basin it has a relatively high Bouguer anomaly (-50 mgals) because of the thick basalt section that fills much of the graben (Mabey, 1976). Consideration of the gravity

values and known structure led Mabey to conclude that the plain is close to isostatic compensation with respect to its margins.

Depth to granite in the western plain graben is not known. A petroleum exploration well 9 km west of Boise drilled 4.4 km of late Cenozoic sediment and basalt and bottomed in volcanic rock that appears from the description of the wellsite geologist to be of intermediate composition. Rock cuttings from the bottom of well have not been

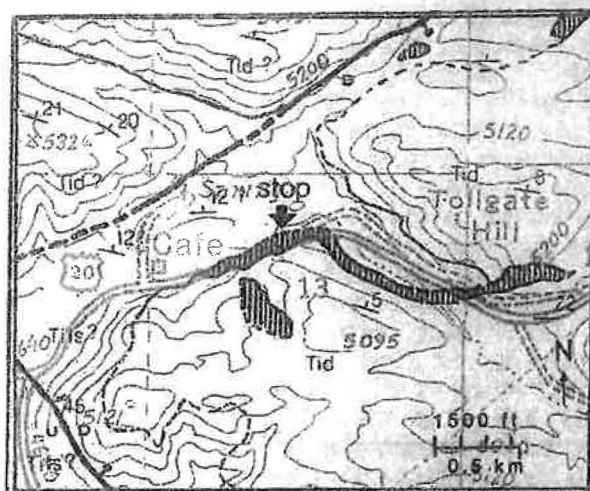


FIGURE 32. Geologic map of the area about the Tollgate stop (mile post 107.5) showing distribution of colorful reddish-orange breccia and black vitrophyre within lithoidal rhyolite units (Tid and Tifs) of north-dipping fault blocks of the Danskin Mountains rhyolites.

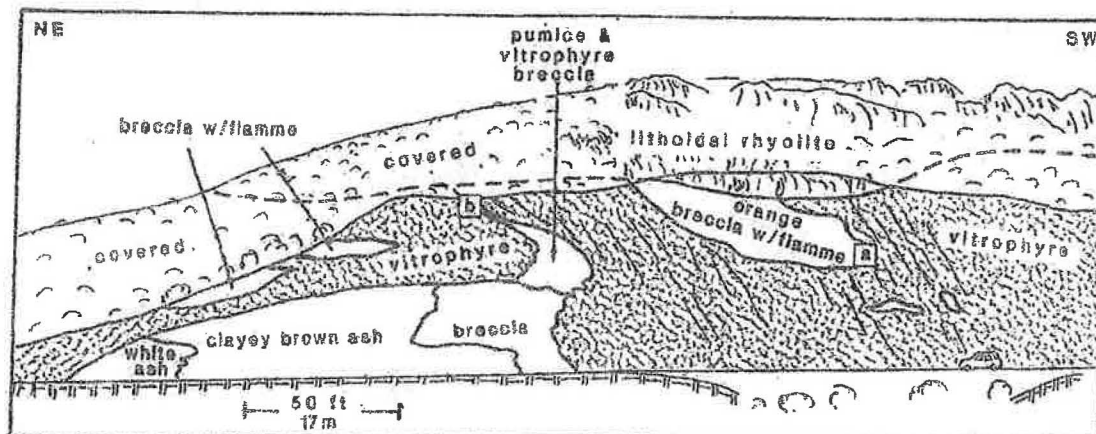


FIGURE 33. Sketch from photo of roadcut at Tollgate stop. View is to the south. Letters "a" and "b" are localities of rocks illustrated in Figure 34.

geochemically analyzed, but the descriptions seem consistent with the occurrence of Eocene and Oligocene calc-alkaline volcanics to the south in the Owyhee Range. In this region of the northern Basin and Range province, intermediate rocks of calc-alkaline composition are older than 22 Ma (Christiansen and Lipman, 1972).

THE SOUTHERN SKYLINE

The skyline due south of the plain is the lowland of the Bruneau-Jarbridge eruptive center, presumably along the "track of the hot spot", and postulated by Bonnichsen, et al., (1987) to be the source of much of the Idavada rhyolite in this part of the Snake River Plain. On a clear day, one can see 150 km to the glaciated peaks of the Jarbridge Mountains in Nevada, a range of Paleozoic and Mesozoic rocks partly covered by Miocene silicic volcanic rocks.

The distant southeast skyline is the basalt-lava covered plain at Twin Falls, beyond which is the dimly visible Albion Range (elevation 10,335 ft), a Cenozoic core complex of Precambrian and younger rocks (Miller, 1980).

THE PLAIN TO THE SOUTH

Plio-Pleistocene Basalt Shields and Flows

The plain to the south is mantled by basalt lavas and shields which, based on their reversed magnetic polarity, are older

than the Snake River Plain Group, and therefore were assigned to the Bruneau Formation (1.0 to 1.9 Ma) by Malde (1987, and in press). Faults and fissures in the prominent shield just south of here trend N70°W, significantly more westerly than the marginal faults of the western plain which trend N45°W.

N70°W is also the trend of a belt of Quaternary basalt vents that extends 90 km across the plain to the west of here (illustrated on route map for field trip). This alignment is significant for two reasons. First, it is 25° more westerly than the N45°W trending marginal normal faults of the western plain graben. Secondly, the alignment contrasts markedly with the alignments of the Quaternary basalt vents and fissures of the eastern plain which are shown by Greeley (1982) to be N10°W to N40°W. If these vent and fissure alignments are extensional features, then they indicate a change in the stress orientation since major faulting of the western plain graben. Furthermore, these alignments indicate that extensional stresses during the Quaternary are different from the eastern plain to the western plain.

VIEW TO THE EAST, SILICIC VOLCANIC ROCKS OF THE EASTERN DANSKIN MOUNTAINS AND THE MOUNT BENNETT HILLS

Mount Bennett Hills on the high eastern skyline are a normal-fault block composed of rhyolite resting upon Mesozoic and early Tertiary granitic rocks of the Idaho

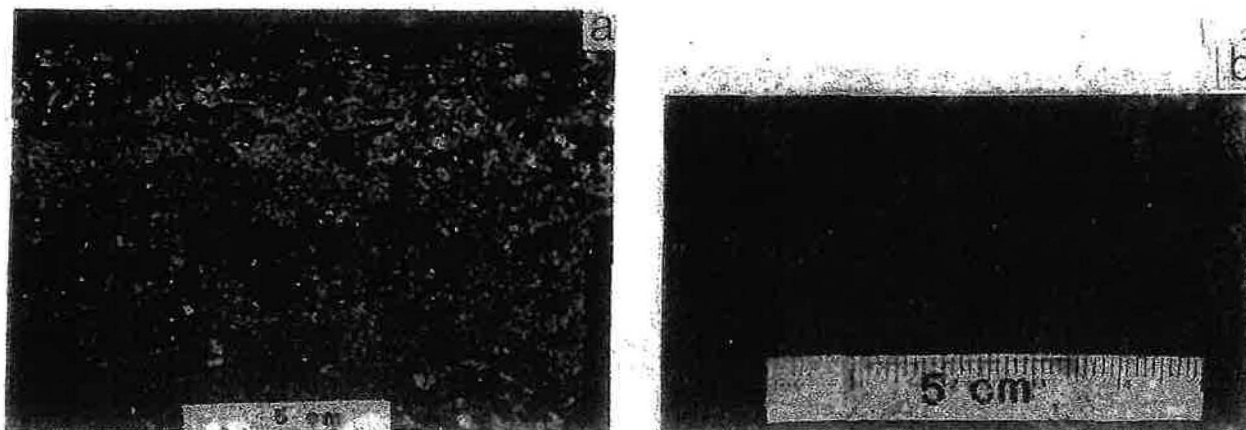


FIGURE 34. Hand specimen of tuff with reddish-orange matrix of welded ash and feldspar phenocrysts, and clasts of fiamme of black vitrophyre from point "a" on Figure 33. (b) Hand specimen of tuff made of porous pumice and angular vitrophyre from zone labelled "b" on Figure 33.

batholith and a patch of Eocene Challis volcanic rocks. The nearby hills are a younger sequence of rhyolites that lapped onto the preexisting Mount Bennett rhyolite block. These relationships and the faulted nature of the northeast margin of the plain are shown in Figure 30.

A single K-Ar date of 11.6 ± 0.6 Ma is published by Armstrong et al. (1980) on a flow unit in the Mount Bennett Block, mapped as the rhyolite of Windy Ridge by Wood and Gardner (1984). The younger flows of the Danskin Range have not been dated; however a similar relationship is reported for the City of Rocks Tuff in the eastern Mount Bennett Hills. The City of Rocks Tuff also onlaps faulted topography of older Idavada rhyolite (Bonnichsen et al., 1988, p.259). Plagioclase separates from the City of Rocks Tuff have been dated by Honjo et al. (1986) at 9.1 ± 0.1 Ma, and this age seems reasonable for the flows in the Danskin Range.

Ekren et al. (1984, p.51-52) examined rhyolites at this same hill and suggested a correlation of the lowest exposed unit, the rhyolite of Frenchman Springs, to the Tuffs of Little Jacks Creek on the south side of the Snake River Plain, based on similar phenocryst content. Two dates on plagioclase from the Tuffs of Little Jacks Creek, 9.6 ± 2.0 , and 10.0 ± 1.5 Ma reported by Armstrong, et al. (1980), support such a correlation. However Ekren, et al. (1984), do not report that the younger Jacks Creek unit laps onto older faulted rhyolite topography. The Jacks Creek unit, however, encompasses many flow units and several polarity reversals, and it does seem likely that some units may eventually be correlated across the plain to this younger sequence of

rhyolites of the Danskin Mountains that has entirely normal magnetic polarity. These problems are being pursued with more detailed petrographic and geochemical work by Norio Honjo at Rice University (Honjo, et al. 1988). At the present time a best age estimate for rhyolite on the Mt. Bennett block is about 11 Ma, and for the younger rhyolites that onlap the block, about 9 to 10 Ma.

Rhyolite at the Top of the Microwave Antennae Hill

Rhyolite on the hill is a part of the Danskin Mountain sequence of younger rocks of normal magnetic polarity. Faulting confuses the relationships on the hill (Fig. 35) but the upper 100m (300 ft) of the hill is composed of the rhyolite of Rattlesnake Springs (10% phenocrysts), resting upon the rhyolite of Frenchman Springs (4% phenocrysts). On the southeast side of the hill, these units are juxtaposed by a fault, with the Rattlesnake Springs unit on the northeast side of the hill and the Frenchman Springs unit on the southeast side.

One can descend from the Microwave relay hill and then walk in an easterly direction across the highway and up the creek to the flow contact between the Rattlesnake Springs unit and the overlying Dive Creek unit (Fig. 36) described as the Stop at Milepost 103.3.

STOP AT MILEPOST 103.3: TURNOFF TO SEE CONTACT BETWEEN RHYOLITE OF RATTLESNAKE SPRINGS WITH RHYOLITE OF DIVE CREEK

A dirt track turns east off the highway and crosses folded and contorted vitrophyre

BENNETT MTN.
elev. 7302 ft.

TEAPOT DOME
elev. 4713 ft.
Twin Falls hot springs



FIGURE 35. Panoramic overview looking southeast across the Snake River Plain from microwave-relay hill. City of Twin Falls is on the southeastern horizon, about 110 km (70 mi) beyond Teapot dome.

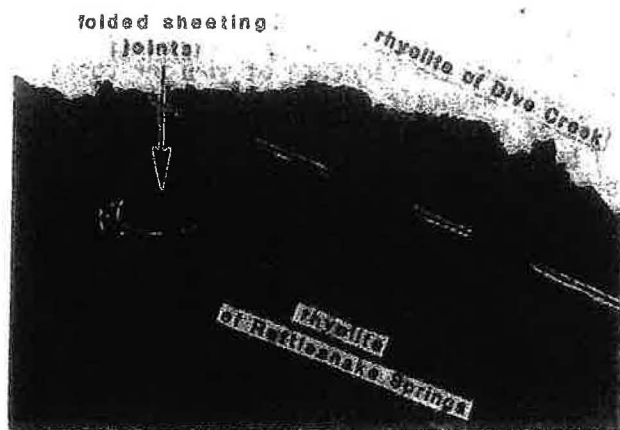


FIGURE 36. Photo of contact between rhyolite of Rattlesnake Springs (10 per cent plagioclase phenocrysts, 1 to 2 mm in size) and rhyolite of Dive Creek (4 per cent plagioclase phenocrysts, 2 to 5 mm in size), as seen at Rattlesnake Springs Creek just east of microwave-relay hill. Uppermost part of the Rattlesnake Springs unit is complexly folded, flowbanded rhyolite and vitrophyre. Base of the Dive Creek unit is lithoidal rhyolite with sheeting and flow banding parallel to the contact.

and devitrified lithoidal rhyolite near the top of the Rattlesnake Springs unit. About 200 m east of the highway is the contact with the overlying Dive Creek unit (Fig.36). Notice the significant difference between units in phenocryst size and abundance. Also note the folded flow-banded top of the Rattlesnake unit and the relatively flat sheeting and flowbanding at the base of the Dive Creek unit. Both of these units are thought to be densely welded ash-flow tuffs, but they are indistinguishable in hand specimen from a flow rhyolite. There is no megascopic pyroclastic material at the contact. This contact suggests that these units are densely welded from top to bottom, and that the lower unit has flowed after remelting.

wildcat well
Griffith-Boatic #1
9676 ft. deep

Jarbridge Mtns.

PLEISTOCENE SHIELD VOLCANO
(Bruneau Formation)
elev. 4004 ft.

eastern
Owyhee
Mtns.

Mountain
Home

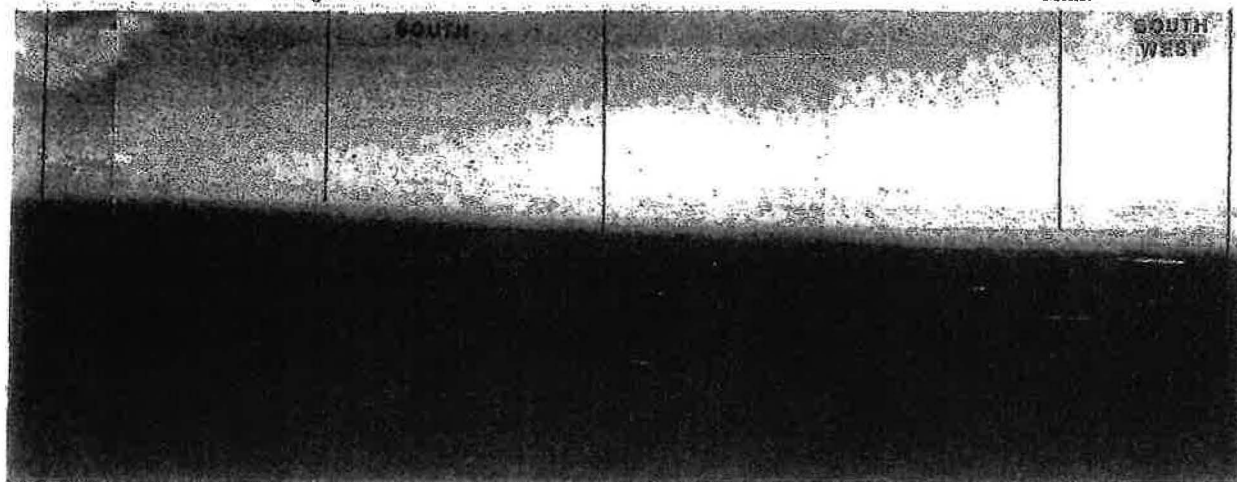


FIGURE 35. (continued)

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