GEOLOGIC MAP OF THE CORE VISITATION AREA OF CRATERS OF THE MOON NATIONAL MONUMENT AND PRESERVE, SOUTH-CENTRAL IDAHO, WITH DESCRIPTIONS OF 38 POINTS OF GEOLOGIC INTEREST

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DESCRIPTION OF MAP UNITS

Note regarding unit symbols Units beginning with a lower case letter are Quaternary units; the "Q" designation has been omitted for space considerations. The first letter of the label for all volcanic units refers to the type of deposit (f=flow deposit, c=cinder deposit, a=ash deposit). The second letter refers to the eruptive period (e.g., a=eruptive period A). The number in the label designates the relative stratigraphic position of the deposit within a given eruptive period (e.g., 1 is younger than 2, etc.). The final letter refers to the type of flow deposit or flow associated deposit (a=a'a flow, p=pahoehoe flow, s=slabby pahoehoe flow, r=rafted blocks, z=squeeze-out flow).

SURFICIAL DEPOSITS

Qca **Colluvium and alluvium (Holocene & Pleistocene)**—Colluvium found at base of steep slopes and alluvium in stream drainages (in lower reach of Little Cottonwood Creek it is as much as 27 m thick).

SNAKE RIVER GROUP (HOLOCENE AND PLEISTOCENE)

Lava flows of eruptive period A

Broken Top flow and related vent and ash deposits (Holocene)

fa1p **Pahoehoe basalt flow**—Broken Top flow is surface-fed from vents, fissures, cracks, and a few small spatter vents on the east and southeast flanks of Broken Top cinder cone. Flow is characterized by hummocky, rough lava with polygonal joints, numerous inflation pits, pressure plateaus, and zones of shelly pahoehoe. This flow has buried portions of the Blue Dragon flow (fa2) and is, therefore, at least slightly younger than the Blue Dragon flow.

ca1 **Broken Top cinder cone**—The bulk of Broken Top cinder cone is thought to have formed during eruptions from the fissure on the west side of the cone, possibly coeval with the Trench Mortar Flat eruptions. West side of cone was actively slumping during formation and displays numerous gravity faults with < 1m offset. Cone is cut by fissures associated with the Trench Mortar Flat event. See expanded interpretation of events in the Broken Top Area at right of unit descriptions.

aa1 **Volcanic ash deposits**—Ash and spatter erupted from vent on west side of Broken Top cinder cone, generally less than 1 m thick.

Blue Dragon flow and related vent deposits (Holocene)

fa2p **Pahoehoe basalt-hawaiite flow—**Dominantly tube-fed and characterized by dark and light-blue glassy, vesiculated surfaces. The flow is comprised of two lobes that came from fissure-controlled vents at the Spatter Cones (ca2) and the southern part of Big Craters cinder cone (ca5).

fa2s **Slabby pahoehoe—**Highly viscous lava that was erupted late in the eruptive sequence, or traversed rough topography or flowed down relatively steep slopes.

ca2 **Spatter Cones—**Composed of agglutinated spatter and cinders that formed around central vents at the southern end of Big Craters cinder cone (ca5). Southern end of fissure system is marked by spatter ramparts and pit craters. Fissure system is source for most of the Blue Dragon flow.

Trench Mortar Flat flow and related vent and ash deposits (Holocene)

fa3p **Pahoehoe basalt-hawaiite flow with volcanic ash deposits**—Trench Mortar Flat flow is a thin, surface-fed flow erupted from the northern part of Trench Mortar Flat eruptive fissure system SE of Big Cinder Butte. Also surface-fed, thin, shelly flows erupted from southern set of fissures northwest of the Watchman cinder cone (ca3). Ash and fine lapilli associated with the Trench Mortar Flat eruptive events are generally <1 m thick.

aa3

fa3s **Slabby pahoehoe flow**—Slabby pahoehoe formed where the Trench Mortar Flat pahoehoe flow continued to flow after its crust had congealed. Slabby pahoehoe also formed from degassed lava erupted directly from the southeast Watchman flank vent.

ca3 **The Watchman cinder cone and other cinder mounds**—Cinder mounds form on either side of the fissure sets associated with the Great Rift along Trench Mortar Flats. These mounds consist of cinder soils, agglutinated spatter deposits, and occasional volcanic bombs. The Watchman cinder cone, the largest of these deposits, is approximately 140 m high and 750 m in diameter.

North Crater flow and related vent and ash deposits (Holocene)

fa4p **North Crater pahoehoe basalt-hawaiite flow**—Highly vesiculated surface-fed flow with blue glassy crust; flow contains xenoliths of gneissic, rhyolitic, and pumaceous rocks.

ca4 **North Crater cinder cone**—North Crater cinder cone was the source for North Crater flow (fa4) and is about 130 m high. Crater is open to the north on northwest side of the cone and the missing wall fragments have been rafted away. North Crater has the greatest diversity of xenoliths (e.g., granulite, Challis volcanics, andesite, and pumice) of any cone in the park. Ash and fine lapilli are discontinuous and less than 1m thick.

aa4

ca4sh **South Highway Cone cinder cone**—South Highway Cone is coeval with North Crater. Most of the cone was destroyed as it was rafted away by trachyandesite flows or swallowed by the collapse back into magma chamber that produced the Highway Fault. Only a sliver of the cone remains on north flank of North Crater. A few prominent remnants of the east side of the cone are left near the North Crater Flow trail parking lot (ca4sh on map). The monoliths on the North Crater Flow Trail are beleived to be volcanic necks that fed the cone.

Big Craters flow and related vent and ash deposits (Holocene)

fa5p **Pahoehoe Hawaiite flow**—Surface-fed flow from eruptive fissures and cinder mantled vents at the north end of Big Craters cinder cone (ca5).

fa5s **Slabby pahoehoe flow**—Slabby pahoehoe formed where partly congealed lava flowed across a rough surface or on a steep slope.

ca5 **Big Craters cinder cone and ash deposits**—Big Craters cinder cone has a complex of at least nine nested craters/vents suggesting a complex eruptive history. Fissure on northern flank sourced Big Craters flows (fa5s and fa5p). Non-eruptive fissures on western flank are parallel to, but offset from main eruptive fissures. Accumulations of ash on the east flank of Big Craters and the west flank of Inferno Cone (c1) are <1m thick.

aa5

Serrate flow (Holocene)

fa6b **Block-a'a trachyandesite flow**—Surface-fed block a'a flow with steep flow fronts as high as 5m; nearly identical to Devils Orchard and Highway flows based on chemistry, petrology and field characteristics.

fa6z **Squeeze-out flows**—Extensive lobes at the base of steep margins of Serrate block-a'a flow.

fa6r **Rafted blocks**—These rafted blocks of crater walls as large as 300 m long and 30 m high most likely came from North Crater and South Highway cones.

Devils Orchard flow (Holocene)

fa7b **Block-a'a trachyandesite flow**—Similar to the Serrate flow (fa6); this flow and the Serrate flow are likely responsible for tearing apart South Highway and North Crater cinder cones. Age relations between this flow and the Serrate and Devils Orchard flows are not known.

fa7r **Rafted blocks**—Broken wall blocks of a shattered cinder cone, probably North Crater and South Highway cinder cones (ca4 and ca4sh). Rafted blocks are as long as 300 m and as high as 20 m.

Highway flow and related vent deposits (Holocene)

fa8b **Block-a'a trachyandesite flow**—Highway flow was surface-fed from a vent area between Grassy and Sunset cinder cones (ce1 and cg1), flow fronts are as high as 15 m.

fa8p **Pahoehoe trachyandesite flow**—Surface-fed glassy flow found in the campground area. Unit consists of slab lava locally.

fa8r **Rafted Blocks**—Source of rafted blocks are most likely North Crater (ca4) and South Highway (ca4sh) cinder cones.

ca8 **Cinder Mounds**—Irregular-shaped mounds less than 8 m high and 100 m in diameter. Origin is unknown but may be related to eruptions associated with North Crater cinder cone (ca4) or South Highway cinder cone (ca4sh) or associated fissures.

Lava flows of eruptive period C

Indian Wells North flow (Holocene)

fc1a **A'a trachyandesite flow**—Steep sided a'a flow with numerous lobes. Flow ridges, furrows, and cracks suggest a source vent near the NW side of Big Cinder Butte (cc3).

fc1r **Rafted blocks**—These rafted blocks of crater walls are as large as 300 m long and 20 m high most likely came from Big Cinder Butte cinder cone (cc3).

fc1z **Squeeze-out flows**—These squeeze-out flows of pahoehoe form bulbous masses at the base of the steep margins of the Indian Wells North a'a flow.

Sawtooth flow and related vent and ash deposits (Holocene)

fc3a **A'a trachyandesite flow**—Sawtooth flow is a surface-fed, steep sided flow that contains numerous lobes with steep fronts. Flow is mantled with as much as 2 m of unmapped ash.

fc3s **Slabby Pahoehoe**—Tumbled, rafted slabs and crusts of pahoehoe. Most of these slabby pahoehoe flows occur as late-stage streams of lava that are between major lobes of the Sawtooth a'a flow. Some of the slabby pahoehoe flows appear to be remobilized regions of the Sawtooth a'a flow.

fc3r **Rafted blocks**—Broken wall blocks derived from Big Cinder Butte (cc3).

fc3z **Squeeze-out flows**—Bulbous masses of pahoehoe form bulbous from rootless vents at base of steep margins of the Indian Sawtooth a'a flow.

cc3 **Big Cinder Butte cinder cone**—Big Cinder Butte cinder cone has a large crator whose walls are mantled by agglutinated spatter and thin lava flows. The Sawtooth flow (fc3) originated from a vent situated within this crater. Stearns (1928) reported that Big Cinder Butte is one of the largest purely basaltic cinder cones in the world with a height of 240 m and a volume of 0·2 km³.

aa3

ac3 **Volcanic-ash deposit**—Ash and lapilli from vents at Big Cinder Butte cinder cone (cc3). Deposits as thick as 1 m occur on the inner crater walls of Big Cinder Butte, and deposits <5 m, although discontinuous, occur on the western and southern flanks of the cone.

South Echo flow related vent deposits (Holocene)

fc4p **Pahoehoe basalt flow**—Thin surface-fed flow that was erupted from fissures between Echo Crater and The Sentinel cinder cones, almost entirely covered by cinders, fine lapilli, and vegetation.

cc4 **Spatter rampart deposits**—Spatter ramparts flank eruptive fissures between The Sentinel and Echo Crater cinder cones; though they are mostly covered with cinders and vegetation, some reach a height of 10 m.

The Sentinel flow (Holocene)

fc7p **Pahoehoe basalt flow**—Surface-fed flow erupted from craters and flank vents of The Sentinel cinder cone (cc7). The flow is almost entirely covered by cinders and thick sagebrush, but there are periodic linear outcroppings of rough pahoehoe lava 1-2 m high, possibly corresponding to old pressure/flow ridges.

cc7 **The Sentinel cinder cone**—About 110 m high and has at least five crater vents suggesting a complex eruptive history. Agglutinated cinder layers tilt away from some craters forming cliffs up to 3 m high. The series of craters roughly parallels the Great Rift.

Lava flows of eruptive period D

Silent Cone flow (Holocene)

fd1p **Pahoehoe trachyandesite flow**—Silent Cone pahoehoe flow is buried proximal to Silent Cone by Big Craters (fa5) and Blue Dragon (fa2) flows; distal portions show numerous distributary lobes.

fd1a **A'a flow**—Silent Cone a'a flow is found in the distal portion of the Silent Cone pahoehoe flow (fd1p) and contains bulbous lobes.

fd1r **Rafted blocks**—Broken wall blocks derived from Silent Cone (cd1).

Little Laidlaw Park flow (Holocene)

fd4a **A'a hawaiite flow**—A'a flow with steep bulbous flow fronts as high as 10m.

Lava flows of eruptive period E

Grassy Cone flow and related vent and ash deposits (Holocene to Pleistocene)

fe1p **Pahoehoe Basalt flow**—Surface and tube-fed pahoehoe flow from source vents at Grassy Cone (ce1). Inflation pits, pressure ridges, and inflation clefts are dominant features of this flow. A'A is found within the collapse pits where the slope of the surface was steepened.

fe1a **Pahoehoe Basalt flow**—Grassy Cone flow is a surface and tube-fed pahoehoe flow from source vents at Grassy Cone (ce1). Inflation pits, pressure ridges, and inflation clefts are dominant features of this flow.

ce1 **Grassy Cone cinder cone and ash deposit**—Consists of 5 nested craters that suggests a complicated eruptive history and is about 110 m high. Ash deposits (ae1) are well bedded ash and lapilli from vents at Grassy Cone and are as much as 1 m thick near the cone.

ae1

Lava flows of eruptive period G

Sunset flows and related vent and ash deposits (latest Pleistocene)

fg1p **Pahoehoe basalt-hawaiite flow**—Sunset flows are surface and possibly tube-fed flows from vents near the Sunset Cone cinder cone (cg1). Sunset NW flow erupted from obscure vents now represented by lava mounds deeply mantled by cinders and ash, that are just NW of Sunset Cone.

cg1 **Sunset Cone cinder cone and ash deposit**—A complex of eight nested craters, which indicates a complicated eruptive history, cone is 140 m high. Well-bedded ash and lapilli on east flank of Sunset Cone (cg1) up to 2 m thick.

ag1

Carey flow (latest Pleistocene)

fg2p **Paoehoe basalt-hawaiite flows**—Flow is believed to have originated from Sunset Cone and flowed 50 km to the southwest.

fg2a **A'a flow**—Carey flow a'a has steep flow fronts as high as 5 m and appears to have formed where Carey pahoehoe flows flowed over steep slopes.

Lava flows of eruptive period H

Cresent Butte flow and related vent deposits (latest Pleistocene)

fh1p **Pahoehoe basalt flow**—Surface-fed, pahoehoe flow that issued from Crescent Butte cinder cone (ch1); majority of flow is vegetated and covered by a thin deposit of colluvium.

ch1 **Crescent Butte cinder cone**—Crescent Butte cinder cone is believed to be the oldest cone in the Craters of the Moon Lava Field. The western side of the cone is covered in ash from Trench Mortar Flat eruptive fissures.

fh2p **Pahoehoe basalt flow**—Surface- and tube-fed pahoehoe flow; vegetated. Source vent is unknown.

Cinder cones of indeterminant age

c1 **Cinder cones (Holocene and latest Pleistocene)**—Cinder cones having no known associated lava flows; absolute ages undetermined. Includes Paisley Cone, Inferno Cone, Half Cone, Echo Crater, Coyote Butte, and other unnamed cones in the northern part of the Monument.

BEDROCK IN MOUNTAINS NORTH OF THE SNAKE RIVER PLAIN

Intrusive rocks

Tg **Biotite Granite of Cottonwood Creek**—Large pinkish-gray rounded outcrops of weathered granite along Goodale's Cutoff, north of the Grassy Cone Pahoehoe flow (fe1p). intrudes into the Challis Volcanic Group.

Volcanic rocks

Challis Volcanic Group (Eocene)

Tcv **Challis Lava-Interbedded Tuff Breccia**—Lava flows and interbedded tuff breccias of Eocene age

Sedimentary rocks

Mcb **Mississippian Copper Basin Formation**—Composed of interbedded claystone, siltstone, sandstone and minor conglomerate. Entire sequence is folded and locally sheared and brecciated.

Contact—Identity and existence certain, location accurate

Contact—Identity and existence certain, location approximate

Normal fault—Identity and existence certain, location accurate. Ball and bar on downthrown block

Rim of volcanic crater—Identity and existence certain, location accurate. Hachures point into crater.

Noneruptive fissures—Fractures in rock through which lava has not erupted. Width generally less than 1 m (3 ft)

Eruptive fissure—Fracture through which lava erupted; generally bordered by spatter ramparts

Lava channel—Large channel, arrow shows direction of flow

Lava Pond—Levees surrounding lava pond; hatchures point away from pond

Pit crater—Generally circular depression formed by collapse; walls are steep to vertical

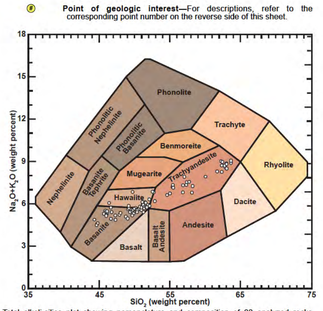
Crater—Crater rim on volcanic vent; hachures point toward central depression (hachures not shown on smaller craters)

Small cone—Vent for small lava cones, cinder cones, and spatter cones

Large cone—Vent for large cones, cinder cones, and spatter cones

Rootless vent—Secondary source of lava not directly related to conduits that brought magma to the surface from deep magma reservoir; chiefly openings along lava tubes

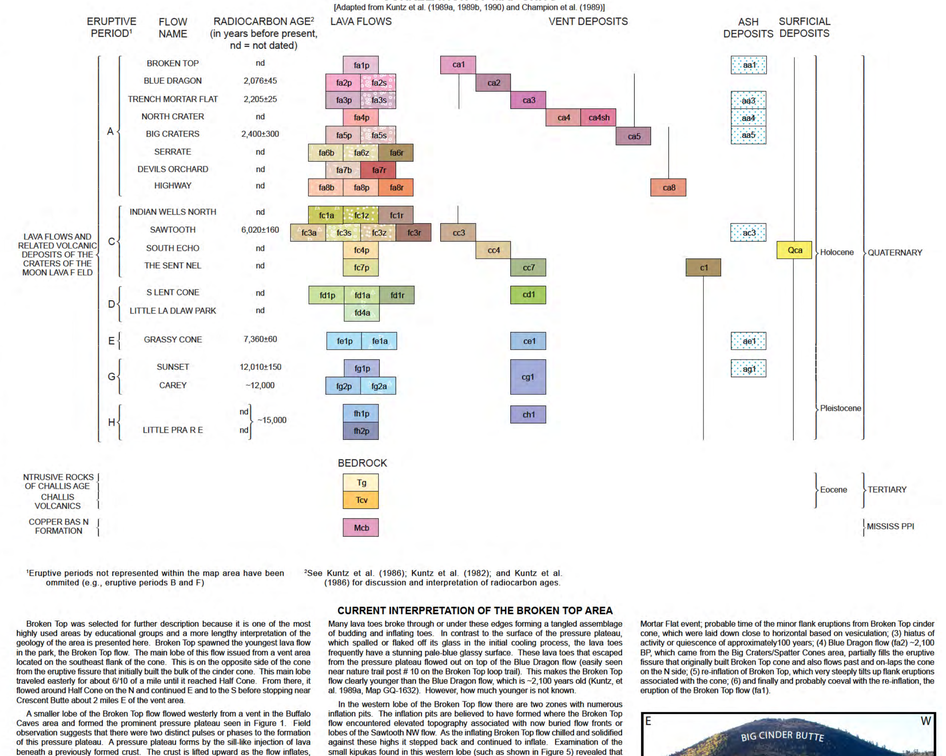
Point of geologic interest—For descriptions, refer to the corresponding point number on the reverse side of this sheet.



Total alkali-silica plot showing nomenclature and composition of 83 analyzed rocks samples from within the map area. Diagram and nomenclature after Cox et al. (1979). Major-element data from Kuntz et al. (1985).

CORRELATION OF MAP UNITS

[Adapted from Kuntz et al. (1988a, 1989b, 1990) and Champion et al. (1989)]



[1]Eruptive periods not represented within the map area have been ommited (e.g., eruptive periods B and F)

[2]See Kuntz et al. (1986); Kuntz et al. (1982); and Kuntz et al. (1986) for discussion and interpretation of radiocarbon ages.

CURRENT INTERPRETATION OF THE BROKEN TOP AREA

Broken Top was selected for further description because it is one of the most highly used areas by educational groups and a more lengthy interpretation of the geology of the area is presented here. Broken Top spawned the youngest lava flow in the park, the Broken Top flow. The main lobe of this flow issued from a vent area located on the southeast flank of the cone. This is on the opposite side of the cone from the eruptive fissure that initially built the bulk of the cinder cone. This main lobe traveled easterly for about 6/10 of a mile until it reached Half Cone. From there, it flowed around Half Cone on the N and continued E and to the S before stopping near Crescent Butte about 2 miles E of the vent area.

A smaller lobe of the Broken Top flow flowed westerly from a vent in the Buffalo Caves area and formed the prominent pressure plateau seen in Figure 1. Field observation suggests that there were two distinct pulses or phases to the formation of this pressure plateau. A pressure plateau forms by the sill-like injection of lava beneath a previously formed crust. The crust is lifted upward as the flow inflates, often tilting up the chilled edges of the flow at a steep angle, which then serve as levees or dikes (Fig. 1). The textures exposed in inflation clefts along the edge of the plateau show the upper 15-40 cm is well vesiculated with horizontal zones/bands of bubbles. This vesiculated zone is interpreted to correspond to the initial outpouring of the flow as a relatively shallow sheet flow. Beneath this vesiculated zone is a much more uniform and massive zone that then extends all the way to the bottom, suggesting that the initial outpouring was followed by a phase of rapid and continuous inflation without distinct surges or pulses to produce new vesiculated zones.

Based on aerial photos and ground observations, the western lobe of the Broken Top flow seems to have been sourced from the vicinity of Buffalo Caves and flowed in a southerly direction from there. Lava stalactites and curbs present at Buffalo Caves also support the interpretation of southerly flow from the Buffalo Cave area based on the direction the lava stalactites on the curbs are bent and the way the accreted material is attached to the curbs (see Figs. 2 & 3). The multi-levels of Buffalo Caves (Fig. 4) suggest that when the initial tube became clogged it built a new one on top, but the eruption and formation of the pressure plateau continued. New tubes are often stacked above the clogged one during an eruption (Gansecki, C. et al., 2003).

The steeply inclined edges of the pressure plateau helped contain what was in essence a small lava lake or pond, but these edges were not perfect levees or dikes.

Many lava toes broke through or under these edges forming a tangled assemblage of budding and inflating toes. In contrast to the surface of the pressure plateau, which spalled or flaked off its glass in the initial cooling process, the lava toes frequently have a stunning pale-blue glassy surface. These lava toes that escaped from the pressure plateau flowed out on top of the Blue Dragon flow (easily seen near nature trail post # 10 on the Broken Top loop trail). This makes the Broken Top flow clearly younger than the Blue Dragon flow, which is ~2,100 years old (Kuntz, et al. 1989a, Map GQ-1632). However, how much younger is not known.

In the western lobe of the Broken Top flow there are two zones with numerous inflation pits. The inflation pits are believed to have formed where the Broken Top flow encountered elevated topography associated with now buried flow fronts or lobes of the Sawtooth NW flow. As the inflating Broken Top flow chilled and solidified against these highs it stepped back and continued to inflate. Examination of the small kipukas found in this western lobe (such as shown in Figure 5) revealed that the Kipukas are actually parts of lobes or flow fronts of the Sawtooth NW flow (age ~6 ka) that were surrounded by the much younger Broken Top flow. These Kipukas also contain rafted cone material transported by the Sawtooth NW flow. Because the Kipukas prove that there are segments of lobes or flow fronts of the Sawtooth NW flow beneath the Broken Top flow, other unseen occurrences of the Sawtooth NW flow beneath the Broken Top flow are the most likely cause for the topographic highs that produced the inflation pits.

Field mapping suggests that near the close of the eruption of the western lobe of the Broken Top flow that there was a significant breakout of lava onto the surface of the pressure plateau. It seems most likely that the breakout represents the clogging/collapse of one or more of the main distributary tubes within the pressure plateau, which then forced the lava back onto the surface. The stacked tubes found at Buffalo Caves give evidence of this type of phenomenon occurring and gives credence to this hypothesis.

The sequence of major events in the Broken Top area is interpreted as follows: (1) Eruption and formation of the unnamed and undated cone (c1) located by the Tree Molds parking lot, eruption and formation of Big Cinder Butte (cc3), and eruption of the Sawtooth NW flow (fc3); (2) cinder mounds N of Big Cinder and also Broken Top cinder cone (ca1) form either slightly before or coeval with the Trench Mortar Flat Event about 2.2 ka; ca1 deposits are cut by fissures associated with the Trench Mortar Flat event; probable time of the minor flank eruptions from Broken Top cinder cone, which were laid down close to horizontal based on vesiculation; (3) hiatus of activity or quiescence of approximately100 years; (4) Blue Dragon flow (fa2) ~2,100 BP, which came from the Big Craters/Spatter Cones area, partially fills the eruptive fissure that originally built Broken Top cone and also flows past and on-laps the cone on the N side; (5) no-inflation of Broken Top, which very steeply tilts up flank eruptions associated with the cone; (6) and finally and probably coeval with the re-inflation, the eruption of the Broken Top flow (fa1).

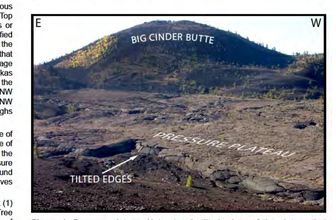


Figure 1. Pressure plateau. Note steeply tilted edges of the plateau that serve as levees to contain the, in essence, lava pond

Figure 2. Bent Lava Curb in Buffalo Caves

Figure 3. Bent lava stalactite in Buffalo Caves

Figure 4. Complicated multi-levels of Buffalo Caves

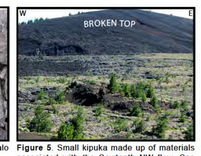
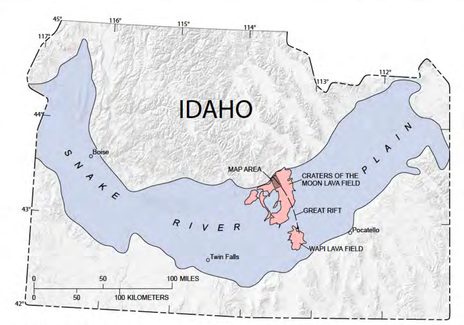


Figure 5. Small kipuka made up of materials associated with the Sawtooth NW flow. See geologic point of interest #23

Figure 6. Fissures from the Trench Mortar Flat event running up Broken Top Cinder Cone



Index hillshade relief map of southern Idaho and the Snake River Plain showing location of the Craters of the Moon and Wapi lava fields, the Great Rift, and map area.

REFERENCES

Barnes, A. C., 2009 Geologic Map of Echo Crater Area, Craters of the Moon National Monument and Preserve: National Park Service, scale 1:12 000, 4 sheets

Brulet, B.R. and Chemtob, S.M., 2006, Geologic Map of Echo Crater Area, Craters of the Moon National Monument and Preserve: National Park Service, scale 1:12 000, 4 sheets

Champion, D.E., Kuntz, M.A., and Lefebvre, R.H., 1989, Geologic map of the North Laidlaw Butte quadrangle, Blaine and Butte Counties, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1634, scale 1:24,000.

Cox, K.G., Bell, J.D., and Pankhurst, R. J., 1979, The interpretation of igneaous rocks: London, George Allen and Unwin, 450 p.

Ganseckj,C., Johnson, J., Hon, K., and Kjargaard, J. 2003. Lava Flows and Lava Tubes: What They Are, How They Form. [Motion Picture] Volcano Video Productions

Kohler, R.M., Mocsny, B.L., Owen, D.E., 2008, Geologic Map of Grassy Cone Area, Craters of the Moon National Monument and Preserve: National Park Service, scale 1:12 000, 4 sheets

Kuntz, M.A., Champion, D.E., Spiker, E.C., Lefebvre, R.H., and McBroome, L.A., 1982, The Great Rift and the evolution of the Craters of the Moon lava field, Idaho, in Bonnichsen, Bill, and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 423–437.

Kuntz, M.A., H.N. Elsheimer, L.F. Espos, and P.R. Klock. 1985. Major-element analyses of latest Pleistocene-Holocene lava fields of the Snake River Plain, Idaho. U.S. Geological SurveyOpen-File Report 85-593, 64 p.

Kuntz, M.A., Champion, D.E., Spiker, E.C., and Lefebvre, R.H., 1986, Contrasting magma types and steady-state, volume-predictable, basaltic volcanism along the Great Rift, Idaho: Geological Society of America Bulletin, v. 97, p. 579–595.

Kuntz, M.A., Spiker, E.C., Rubin, Meyer, Champion, D.E., and Lefebvre, R.H., 1986, Radiocarbon studies of latest Pleistocene and Holocene lava flows of the Snake River Plain, Idaho—Data, lessons, interpretations: Quaternary Research, v. 25, p. 163–176.

Kuntz, M.A., Lefebvre, R.H., Champion, D.E., Skipp, B.A., 1989a, Geologic map of the Inferno Cone quadrangle, Butte County, ID: U.S. Geological Survey Quadrangle Map GQ-1632, scale 1:24,000.

Kuntz, M.A., Lefebvre, R.H., and Champion, D.E., 1989b, Geologic map of the Watchman quadrangle, Butte County, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1633, scale 1:24,000.

Kuntz, M.A., Champion, D.E., and Lefebvre, R.H., 1990, Geologic map of the Fissure Butte quadrangle, Blaine and Butte Counties, Idaho: U.S. Geological Survey Geologic Quadrangle Map GQ-1635, scale 1:24,000.

Rivera, T.A., Keane, S.M., and Owen, D.E., 2007, Geologic map of the Visitor Center Area, Craters of the Moon National Monument and Preserve: National Park Service, scale 1:12 000, 6 sheets

Tveter, A.J., Shirley, E.K., Owen, D.E., 2009, Geologic Map of Broken Top Area, Craters of the Moon National Monument and Preserve: National Park Service, scale 1:12 000, 8 sheets

Stearns, H.T., 1928, Craters of the Moon National Monument, Idaho: Idaho Bur. Mines and Geol: Bull, v. 13, 57 p.

Wetherell, K. A., Clennon, R. P., Truitt, K. E., and Hansen, N., 2005, Geologic map of the Broken Top area, Craters of the Moon National Monument and Preserve: National Park Service, scale 1:12 000, 2 sheets

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