

Geologic Assessment of the Broken Top Loop Trail Project

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Geologic Setting:

The Craters of the Moon Lava Field is the largest basaltic, dominantly Holocene lava field in the lower 48 states. Between approximately 8 and 10 million years ago the Yellowstone Hotspot was beneath Craters of the Moon. This time was characterized by violent rhyolite eruptions and caldera formation. Between 6 million and 15,000 years ago numerous basaltic eruptions produced a 4,000-foot-thick sequence of lava flows. Between about 15,000 and 2,000 years ago the Craters of the Moon Lava Field formed during eight major eruptive periods. During this time the Craters of the Moon lava field grew to cover 618 square miles. The Craters of the Moon Lava Field, a composite field, is made up of about 60 lava flows and 25 cones. It is the largest and most complex of the late Pleistocene basaltic lava fields of the Eastern Snake River Plain. It has nearly every type of feature associated with basaltic systems (see next section for examples). The flows of the Craters of the Moon Lava Field have parent magma similar to that in the rest of the plain, but exhibit a wide range of chemical compositions. This wide range is caused in one of two ways: (1) by crustal contamination from assimilating older rocks, which produces lava with silica (SiO_2) ranges of ~49% to 64%, or (2) by crystal fractionation, which produces lava with silica ranges of ~44% to 54%.

The Craters of the Moon lava field lies along the Great Rift. The Great Rift is a system of crustal fractures. It begins at the base of the Pioneer Mountains (north of the park's visitor center) and extends for over 50 miles to the southeast. The Craters of the Moon Lava Field is the northernmost of the 3 lava fields found along the Great Rift. The Craters of the Moon Lava Field formed from magma which pushed up along the Great Rift. The Great Rift and other volcanic rifts on the Eastern Snake River Plain are generally parallel to, but not necessarily collinear with basin and range faults north and south of the plain.

Geologic Features:

Craters of the Moon has nearly every type of feature associated with basaltic volcanism. This and the next 3 paragraphs are a sampling of some the features that are present. Most of the Craters of the Moon lava flows are pahoehoe and were fed through tubes and tube systems, although there are some sheet flows. At Craters of the Moon structures representing both inflation and deflation of the lava surface can be seen along with hot and cold collapses of the roofs of lava tubes. Inside lava tubes one can see lava stalactites, remelt features, and lava curbs. In other places lava flows formed ponds, built levees, and produced lava cascades. Some lava flows produced small mounds (*tumuli*) or elongated ridges (*pressure ridges*) on their crusts. In some places squeeze-ups formed when pressure was sufficient to force molten lava up through tension fractures in the top of pressure ridges or cracks in the solidified crust of lava ponds. Pressure plateaus were produced by the sill-like injection of new lava beneath the crust of an earlier flow that had not completely solidified.

Some lava flows were very dense and had a surface of angular blocks—*block lava*. Others had a rough, jagged, or clinkery surface—*áa lava*. Still others had a smooth, ropy, or billowy surface—*pahoehoe lava*. Three special kinds of pahoehoe may be observed in the Craters of the Moon Lava Field: (1) *slab pahoehoe* or slab lava, also known informally as *semihoe*, is made up of jumbled plates or slabs of broken pahoehoe crust; (2) *shelly pahoehoe*, which forms from gas-charged lava, contains small open tubes, blisters, and thin crusts; and (3) *spiny pahoehoe*, which was very thick and pasty, contains elongated gas bubbles on the surface that form spines. The spiny variety was pahoehoe in a transition phase to *áa*.

Numerous times fire fountains shot highly gas-charged molten rock to heights of over 1,000 feet and rained down to form the many cinder cones found in Craters of the Moon. Big Cinder Butte, the tallest cinder cone at Craters of the Moon, is over 700 feet high and is located just to the south of Broken Top. Some vents along the rift ejected very fluid particles (*spatter*) that accumulated to form steep-sided *spatter cones*. When a whole segment of rift or eruptive fissure erupted, spatter accumulated to produce low ridges called *spatter ramparts*. *Hornitos*, also known as rootless vents, are similar in appearance to spatter cones. Hornitos form from spatter ejected from holes in the crust of a lava tube instead of directly from a feeding fissure. Craters of the Moon also has collapses known as *sinks* or *pit craters*. During some eruptions pieces of crater walls were carried off like icebergs by lava flows. These wall chunks are known as *rafted blocks*.

Four kinds of bombs are found at Craters of the Moon, all of which start off as globs of molten rock thrown into the air. If the glob gets twisted during its flight it is called a *spindle bomb* and typically extends from a few inches to several feet in length. If it is very tiny and twisted it is called a *ribbon bomb*. When a glob forms a crust as it flies through the air and if the gases inside continue to expand and crack that crust, it is called a *breadcrust bomb*. The outer surface texture is similar to bread rising in the oven. If the glob does not completely solidify during flight, so that it goes splat and flattens on landing, it is called a *cow-pie bomb*. Some cow-pie bombs are over 10 feet long.

Geology in the Broken Top Area:

Broken Top is one of the youngest volcanic cones within the Craters of the Moon lava field based on stratigraphic relationships (i.e. the Blue Dragon flow wraps around the spatter rampart on the S edge of the eruptive fissure that helped build the Broken Top cinder cone and partially in-fills the fissure). It is slightly older than the Blue Dragon Flow ($\cong 2,100$ BP). On the same basis, the Broken Top flow is the youngest flow, being slightly younger than the Blue Dragon flow. One of the proposed alternate routes for the Broken Top Loop Trail would skirt the base of Big Cinder Butte, pass by flow fronts of the Sawtooth flow and rafted blocks from Big Cinder, and return along the flank of the unnamed cone by the parking lot. All of these features along the proposed alternate route are believed to be part of the 6,000-year-old eruptive period. The Sawtooth flow has been dated at $6,020 \text{ BP} \pm 160$.

The Blue Dragon flow in the area is replete with textbook examples of slab and spiny pahoehoe. The Broken Top flow exhibits textures suggesting both very hot and fluid flow as well as more intermediate viscosities. Portions of the Broken Top flow are extremely good examples of shelly pahoehoe. Blisters, toes, tumuli, pressure ridges, inflation and deflation structure, lava ropes and billows are all present within the study area. All four types of volcanic bombs described in the geologic features section are present. Eruptive and non-eruptive fissures, examples of flank eruptions, and a classic pressure plateau are present. There are rafted blocks from both Broken Top and Big Cinder Butte present in the study area. This area has the best assemblage of geologic features for educational purposes within a reasonable distance of one another in this end of the monument.

Current Geologic Resource Conditions of the existing Loop Trail:

Parking Lot to Wilderness Trail Head—the classic slab pahoehoe or slab lava along the road has had negligible impact from visitors over the years probably owing to its extreme roughness discouraging anyone from trying to cross it.

Wilderness Trail Head to entry into open Limber Pine forest—other than compaction and minor rill erosion that occurs along the trail periodically after a thunderstorm, there is no apparent degradation of geologic resources. It is possible that some bombs may be missing from the lower portion of this trail segment where they occur more commonly.

Entry into the forest to the NE corner of loop—this trail segment follows the old sheepherders' road and was also driven by NPS prior to wilderness designation in 1970. In 30 years the plants have reclaimed much of the road width. At approximately the exit from the open forest area, an old barrow pit area is still visible. Beyond this a sizeable bank of iridescent cinders remains largely undisturbed aside from the bench cut for the old road. This is despite many years of visitor use for those heading to the wilderness, daily guided walks in the summer, and use by 1,000's of school children every year for several years.

NE corner to Buffalo Caves turn off—this segment, which follows the old road, appears to have narrowed over the past 30 years through down slope movements of cinders from human and deer traffic, as well as the ubiquitous pull of gravity. The lava toe area at the base of the slope has had some significant damage to the glassy crusts of the lava exposing the oxidized zone beneath. *(It is recommended that a low lodgepole pine fence be placed as a barrier to discourage people from walking on them—no option under consideration would reroute the Wilderness Trail or Broken Top Loop Trail from going by them and they need protection from further damage.)*

Buffalo caves turn off to Buffalo Caves—this segment is generally in good condition, with the exception of the feature called "Dumbo", which has had a portion of the front leg removed, possibly by the NPS to build rock cairns. The cave area is in good condition and has outstanding lava curbs, stacked tubes, and hot and cold collapse features. The backdoor has an unstable ceiling, which has been closed for visitor safety. Lava stalactites and sulfate crystals adorn much of the ceiling within the cave. No human induced damage is readily apparent to these features even after over 70 years of use.

Buffalo Caves to Eruptive Fissure—this segment passes the steep up tilted edge of the pressure plateau or lava lake and is the best example readily available to the public in this end of the monument. The trail passes non-eruptive fissure on the flank of Broken Top and a long lava toe or finger that has natural Bonsai. The crust on the finger shows some damage and a lodgepole fence now serves to discourage further damage and protect the Bonsai. Crusts on some of the cow-pie bombs in close proximity to the trail show minor damage attributed to foot traffic. A viewing area delimited by a low lodgepole fence has been erected to protect a textbook example of inflation structure with offset ropes and a striated slip face. There has been no damage to the feature and nearby glassy crusts have also been protected by the fenced off viewing area. A classic series of pahoehoe ropes has also been fenced with lodgepole and is in pristine condition.

Edge of eruptive fissure to backside of spatter rampart—trail crosses a very rough section of Blue Dragon flow that partially fills the eruptive fissure. The first portion of the segment follows the contact between the Blue Dragon flow and breakouts from the pressure plateau of the Broken Top flow. This rough segment is about 280 feet long and was delineated with lodgepoles a few years back because of the difficulty people were having following the trail. This difficulty resulted in significant damage to fragile crusts over a disperse area. The lodgepoles, from observations by NPS personnel, seem to be working well to focus foot traffic across the proscribed trail.

Rampart to Road—lava billows at the start of this segment show some damage and were railed off with lodgepole several years ago to deter further damage. From the billows to the road minor damage to glassy crusts on the Blue Dragon are evident in places. The trail was rerouted around the two segments with the most damage so that the trail now follows cinders areas rather than crossing the lava directly.

Current Geologic Resource Conditions and Possible Environmental Consequences of Trail Alternatives and proposed improvements:

- (I) Parking Lot to Wilderness Trail Head—construction of a sidewalk along the SE side of the road will largely be built on cinders that were brought in during the construction of the road. By not having the sidewalk on the NW side of the road where it would be in close proximity to the slab pahoehoe, which does have some nice blue glass on it in places, it is likely to assure continued resource protection. (Note: people have walked the road on either side for dozens of years without significant impact).
- (II) Spur to proposed overlook—proposed spur follows a course across cinders with Sagebrush, Bitterbrush, and Rubber Rabbitbrush shrub communities. Shrubs would need to be removed along the path (*perhaps some could be used to re-vegetate the barrow pit area?*). Anticipated consequence is compaction of cinders within the footprint of the spur trail.

(III) Alternate return from edge of eruptive fissure to road—from a geologic standpoint this seems ill advised. The slope immediately next to the proposed segment is dominantly in excess of the normal angle of repose for cinders. It is armored by spatter, which periodically has failed resulting in rock fall and the accumulation of debris at the base of the slope. A trail in this area would put visitors in the path of potential rock fall. A significant amount of external fill would be required and because of the heavy equipment to be used, produce a broad path burying the original lava surface.

(IV) Return from Wilderness Trail via base of Big Cinder Butte to Parking Lot:

- (A) Segment from Wilderness Trail to main body of the Broken Top flow (pressure plateau or lava lake) south of Broken Top—this segment follows a low cinder hill back towards Buffalo Cave, but further south than the existing trail. This area is pristine and strewn with all types and sizes of volcanic bombs. Many of the bombs are of relatively small size and would be easy to walk off with. An additional concern is that people already at Buffalo Caves would be tempted to short cut directly to this segment of trail if they saw people on it, rather than backtracking to the wilderness trail to pick it up. It is foreseeable that over time a series of social trails might develop. Prior to reaching the lava, a segment of the rift that runs between the non-eruptive fissure on Broken Top and the non-eruptive fissure on the NE flank of Big Cinder is crossed by the trail. Parts of this rift have been eruptive and the ground is treacherous. Right next to the proposed trail I found a section that collapsed with light pressure from a hiking staff and a resource person broke through to a hollow leg deep while walking across it. For safety, the trail in this area should be a boardwalk or at least should be probed for stability and well delineated to assure visitor safety.
- (B) Edge of lava to edge of Big Cinder—this segment, which crosses the top of the pressure plateau, is not particularly vulnerable to damage from walking across it, because most of it lost its glass early in its history. Nevertheless, it would still require something to delineate the trail and confine traffic to the trail corridor. Approaching the edge near Big Cinder there are squeeze-ups, much like what was called "Devil's Sewer" which was lost to vandals near North Crater Flow Trail. There is at least one pipe like squeeze-up covered with blue glass in that area that might be a tempting target for someone to try and remove, though it is likely that all they would succeed in doing is destroying it in the process. Some fractures in the area also support healthy groups of Christmas Ferns.
- (C) Edge of Big Cinder back to Parking Lot—this segment of the trail passes along the north edge of Big Cinder, by several flow fronts of the Sawtooth flow, and by rafted blocks from Big Cinder. The first half of this segment along Big Cinder is dominantly pristine (a few sawed off branches on a couple of the Limber Pines indicates that parts of this path have been used before). The area is strewn with breadcrust, spindle, and ribbon bombs that might prove too great a temptation to take home by some visitors. There appears to be a quarry site some distance from the proposed trail on one of the

Sawtooth flow fronts. Arrowheads and flaked material have been found in the transition zone between Big Cinder and the unnamed cone by the parking lot that is along the proposed trail route. Some of the material I have found is obsidian and not from this area. Also, people might be tempted to short cut from the tree molds trail to this segment and visa versa upon seeing other people. This could result in a number of social trails developing over time.

Recommendations/evaluation based on geologic observations:

- (1) Sidewalk from parking lot along the road to the trailhead would cause no significant disturbance/impact to any geologic features.
- (2) Spur trail to viewing platform/viewing area would cause no significant disturbance/impact to any geologic features.
- (3) Alternate return from the edge of the eruptive fissure to the road represents a potential geologic hazard to visitors and a significant impact to geologic resources due to the large amount of fill that be placed on top of the lava flow.
- (4) Alternate route from wilderness trail back to parking lot via Big Cinder represents a potential geologic hazard in the rift area. Potential impact to geologic features such as volcanic bombs and squeeze-ups by establishing a formal trail is high. The large amount of materials required to delineate the trail across the Broken Top flow would create a considerable impact to the view shed. Potential for other social trails developing is high. Recommend keeping this as a possible route for special guided ranger walks, but not developing this as a formal route or trail.
- (5) Other than 1 & 2 above, recommend improving the existing loop trail where impacts have already occurred, and some remedies have already been put in place. Biggest concern with the existing trail is safety related to the 280-ft. rough segment between edge of the eruptive fissure and the backside of the rampart. Suggest wood stairs and boardwalk like Yellowstone has so successfully used in the Mud Volcano Area and for the decent to view the lower falls be considered. Even a simple handrail painted to blend in with surroundings in lieu of steps would be a big improvement.

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