# Geological Field Trips in Southern Idaho, Eastern Oregon, and Northern Nevada

Edited by Kathleen M. Haller and Spencer H. Wood



Open-File Report 2004-1222

**U.S. Department of the Interior**
**U.S. Geological Survey**

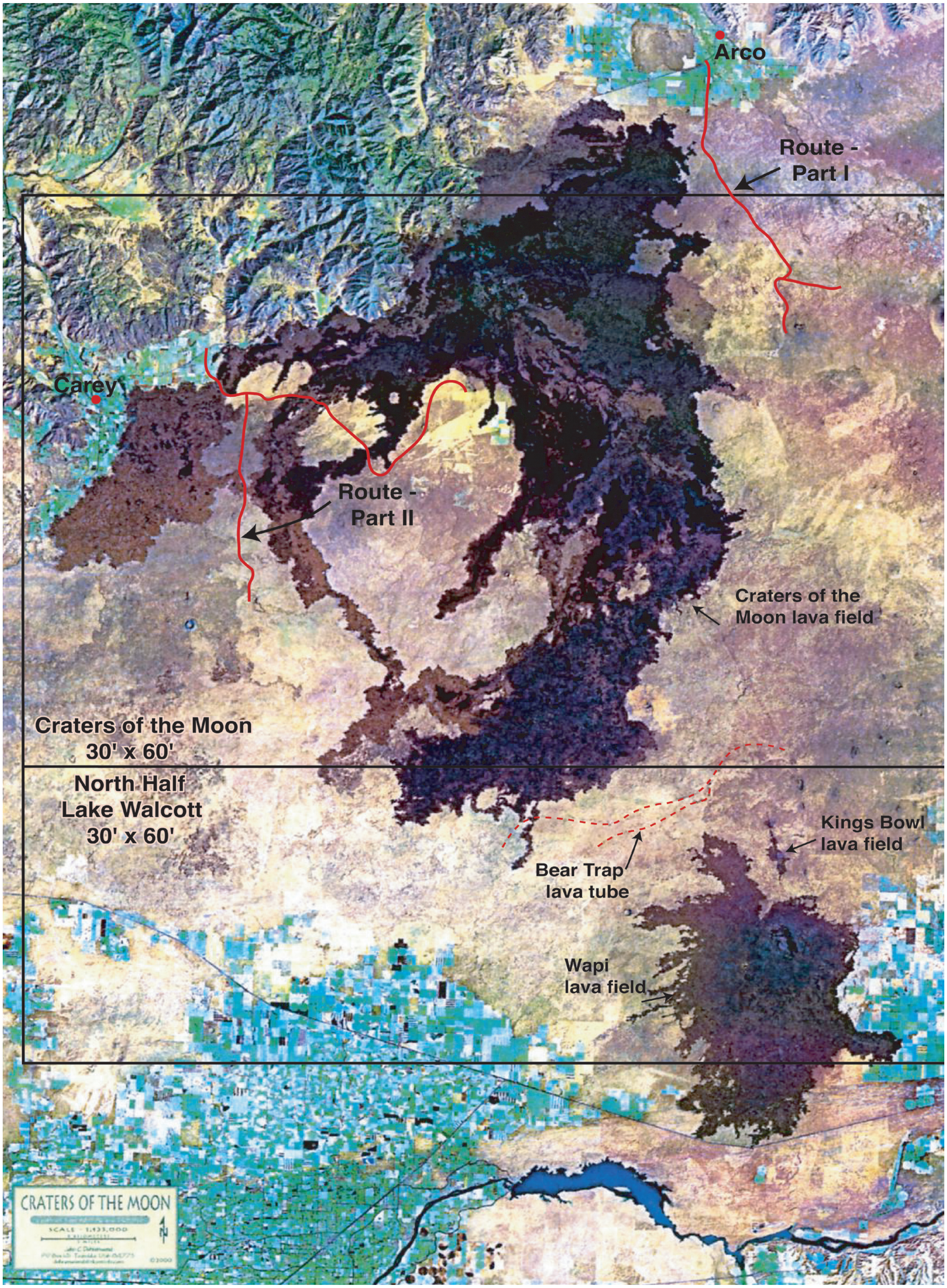


Figure I-1. Landsat-7 image of the Craters of the Moon, Kings Bowl, and Wapi lava fields. Shown on figure are routes of Parts I and II of this road log and boundaries of the Craters of the Moon and the northern half of the Lake Walcott 30′ x 60′ minute quadrangles. Image prepared by John Dohrenwend, P.O. Box 141, Teasdale, Utah, 84773. dohrenwend@rkymtnhi.com.

# Geology of the Craters of the Moon 30′ X 60′ Map Area and New Perspectives on Basaltic Volcanism of the Eastern Snake River Plain, Idaho

By Mel A. Kuntz[1], Douglass E. Owen[2], Duane E. Champion[3], Phillip B. Gans[4], Sara C. Smith[5], and Cooper Brossy[5]

## Introduction

Basaltic volcanism was a dominant geologic process in the eastern Snake River Plain (ESRP) in Holocene time, as attested by the fact that eight dominantly late Pleistocene and Holocene (<15 ka) lava fields cover about 13 percent of the ESRP.

Because widespread loess deposition essentially terminated at the end of the late Pleistocene, probably owing to abrupt climate change due to retreat of continental and alpine glaciers, the dominantly Holocene lava fields are relatively loess free and have low reflectance in Landsat satellite images (fig. I-1). Three of these lava fields, Craters of the Moon, Kings Bowl, and Wapi, lie along the Great Rift volcanic rift zone. The Great Rift volcanic rift zone is an 85-km-long and 2- to15-km-wide belt of tephra cones, lava cones, shield volcanoes, eruptive fissures and associated tephra deposits, and noneruptive fissures. These three, dominantly Holocene lava fields and the volcanic structures of the Great Rift volcanic rift zone lie within the Craters of the Moon 30' x 60' quadrangle and the northern half of the Lake Walcott 30' x 60' quadrangle (fig. I-1).

The Craters of the Moon National Monument was established by President Coolidge on May 2, 1924. Since 1924, the Monument has been expanded through five presidential proclamations. The most recent and largest expansion of the Monument occurred on November 9, 2000, when President Clinton signed a proclamation enlarging the Monument 13-fold, from 55,000 acres to 715,000 acres. The expanded Monument assures the protection of the entire Great Rift volcanic rift zone. It encompasses all of the Craters of the Moon lava field as well as remote areas that include the Kings Bowl lava field, Wapi lava field, and the Bear Trap lava tube. The Monument is managed cooperatively by the National Park Service and the Bureau of Land Management. The National Park Service has primary management authority over the portion of the Monument that includes the dominantly Holocene lava fields (Craters of the Moon, Kings Bowl, and Wapi). The Bureau of Land Management has primary management authority over the remaining portion of the monument. A Visitor Center, camping facilities, and the best access for sightseeing and hiking in the Craters of the Moon lava field are provided by the National Park Service at the north end of the Monument, located off U.S. Highway 20-26-93 between Arco and Carey.

### Focus of Field Trip

The geologic map of the Craters of the Moon 30' x 60' quadrangle has now been published by the U.S. Geological Survey (Kuntz and others, in press). The map details the northern part of the Craters of the Moon lava field, especially near the Visitor Center and most easily accessible parts of Great Rift volcanic rift zone. This map now places the Craters of the Moon lava field within a larger framework of accurately dated and correlated, pre-Holocene basaltic volcanism in the ESRP.

The Craters of the Moon (COM) 30' x 60' map was published previously as a USGS Open-File map (Kuntz and others, 1994). On this map, the detailed geology of the northern part of the Craters of the Moon lava field was shown, based on detailed mapping, paleomagnetic studies, and radiocarbon dating (see Kuntz and others, 1994, and references therein). On the Open-File map, all surrounding lava fields were identified simply as "pre-Holocene lava fields", because little accurate and precise radiometric dating had been conducted in this area. With the expansion of the Monument in 2000, funds became available from the National Park Service and the Bureau of Land Management to support additional paleomagnetic studies and $^{40}Ar/^{39}Ar$ dating. The completion of the geologic map of the Craters of the Moon 30' x 60' quadrangle is due in part to these two agencies. We acknowledge their support and encouragement. We hope that the Craters of the Moon quadrangle map and the forthcoming map of the northern half of the Lake Walcott 1:100,000-scale quadrangle will be important contributions for management of the expanded Monument as well as for the broad-scale understanding of the basaltic-volcanic evolution of the ESRP.

The combined field, paleomagnetic, and $^{40}Ar/^{39}Ar$ studies have given detail to the pre-Holocene lava fields that surround and lie within kipukas (areas of older lava flows surrounded

[1]U.S. Geological Survey, Denver, CO 80225, mkuntz@usgs.gov

[2]Craters of the Moon National Monument and Preserve, Arco, ID 83213

[3]U.S. Geological Survey, Menlo Park, CA 94025

[4]Department of Geology, University of California, Santa Barbara, CA 93106

[5]Bureau of Land Management, Shoshone, ID 83352

by younger lava flows) of the Craters of the Moon lava field. In addition, these studies now permit a more detailed analysis of the timescales for tectonics and basaltic magmatism for an important part of the ESRP. In a sense, these data can be used to determine the late and middle Pleistocene and Holocene "pulse rate" for basaltic volcanism for the Craters of the Moon lava field and lava fields that surround the Craters of the Moon field. These data show that a major volcanic rift zone, the Borkum rift zone, which contains vents at Sand Butte and Broken Top Butte, was active about 50 ka on the western margin of the Craters of the Moon lava field. A second region of young basaltic volcanism was active about 65–12 ka in the Arco-Big Southern Butte and Rock Corral Butte volcanic rift zones that lie east of the Craters of the Moon lava field (fig. I-1).

The focus of this field trip is to examine the setting of Holocene and late Pleistocene basaltic volcanism in the Craters of the Moon 30' x 60' area. The field-trip guidebook is presented in three parts. Part I will focus on late Pleistocene lava fields that lie east of the Craters of the Moon lava field in the Quaking Aspen Butte-Big Southern Butte area. This area is easily accessible on the Arco-Minidoka road (assuming good weather and dry roads) from 15 to 25 km south of Arco, Idaho. Part II will focus on late Pleistocene basaltic volcanism that lies west of the Craters of the Moon lava field in the Sand Butte-Laidlaw Park area. These latter two areas are easily accessible via the Carey-Kimama and Laidlaw Park roads. Part III will focus on new studies of various aspects of the Holocene basaltic volcanism of the Craters of the Moon lava field.

## Travel Recommendations and Warning!

Travel on nonpaved roads in the ESRP is potentially very dangerous. This area is one of the most remote parts of the lower 48 states. You can travel roads in this part of Idaho for days without seeing another vehicle or person.

Type of vehicle, tire type and quality, and weather conditions must all be ideal to attempt travel on the roads described in this field-trip guide. **Four-wheel drive vehicles** with high clearance are strongly recommended. **Tires** should be of good quality; 6-ply and 8-ply tires with strong sidewalls are highly recommended. Typical tires on passenger sedans are much too weak for backcountry roads. If you should have a flat tire on a backcountry road, replace the tire and promptly, but **slowly,** drive to the nearest paved road. Do not tempt fate without a spare tire. Travel should be attempted only in times of **ideal weather conditions** (*i.e.*, when roads are dry and weather forecasts do not include the possibility of rain or snow). Travel on these roads in spring and early summer, when the roads are wet, can easily lead to vehicles becoming stuck in water-saturated, gumbo-like road materials. Backcountry roads typically are constructed of loess and gravel; loess becomes very sticky and slippery when wet. During the summer months and hot weather, it is advisable to travel in an air-conditioned vehicle. Keep windows closed and air conditioning on in order to create positive air pressure in the vehicle to keep out air-borne loess. **Always have a cell phone** in your vehicle. Many backcountry roads in the ESRP do not have cell phone coverage at road level, but coverage generally can be obtained by climbing to the top of a nearby hill or butte. **Always travel with extra food and water**. If you become stranded in the middle of the ESRP, you face a 10–50 km walk to the nearest paved road and some semblance of civilization. Potential problems can be also be alleviated if you also **carry a GPS receiver and maps that contain latitude-longitude and/or UTM coordinates**, such as 1:24,000-scale and 1:100,000-scale USGS topographic maps. If you become stranded, determine your location on a map, determine where roads lead, and how to find the quickest and shortest route to a paved road. In short, vehicle travel on backcountry roads in the ESRP can be enjoyable, educational, and entertaining, but it is not for the faint of heart. Follow these recommended safety precautions.

# FIELD-TRIP ROAD LOG

## Part I: Pre-Holocene Basaltic Volcanism of the Eastern Part of the Craters of the Moon 30′ x 60′ Quadrangle

The route of Parts I and II of the field trip may be followed on one of several maps, including the Craters of the Moon 30' x 60' topographic map, the Geologic Map of the Craters of the Moon 30' x 60' quadrangle, various USGS 1:24,000-scale topographic maps, and on figure I-1.

| Mileage Inc. | Cum. | |
|---|---|---|
| 0.0 | 0.0 | START: Junction of U.S. Highways 20-26-93 in downtown Arco, Idaho. Proceed south on U.S. Highway 20-26 through Arco. Low flat ground on path of highway is Holocene flood plain of Big Lost River. |
| 1.8 | 1.8 | Cross Big Lost River. |
| 0.3 | 2.1 | Turn south on 3100 West Road (Arco-Minidoka Road). |
| 0.2 | 2.3 | Road rises onto upper Pleistocene, Pinedale-age terrace deposits on west side of Big Lost River. Unit covered by approximately 1–2 m of loess, which is exposed in borrow pit to west (right). Note very flat surface of unit; runways of Arco airport are located on this unit 1.5 km west. Extensive farming of potatoes, hay, and alfalfa for next several kilometers are on loess that covers this unit. |

| Mileage Inc. | Cum. | |
|---|---|---|
| ~2.0 | ~4.3 | Gooddales Cutoff (a branch of the Oregon Trail that began at Fort Hall, crossed the ESRP from Springfield, Idaho, to Big Southern Butte, and then traversed the northern side of the Snake River Plain) crosses 3100 West Road at approximately this point. Evidence of the emigrant trail at this locality now is destroyed by farming, but trail ruts can be easily recognized 1.5 km east and about 2 km west of this point. |
| 0.7 | 5.0 | Edge of terrace. Sediment in low area for next 0.6 km is alluvium deposited along a tributary of the Big Lost River that followed contact of the south edge of terrace deposit and basalt flows to the south. |
| 0.4 | 5.4 | Road rises onto basalt flows of the Wildhorse Butte lava field. Vent at Wildhorse Butte is located approximately 9 km south, just slightly east (left) of due south at about 11:30 o'clock on the horizon, just to the right of Big Southern Butte. $^{40}Ar/^{39}Ar$ age for Wildhorse Butte lava field is 325±10 ka. |
| 1.0 | 6.4 | Cattle guard and kiosk that describes the newly expanded, NPS-BLM, jointly-managed Craters of the Moon National Monument. |
| 0.4 | 6.8 | Bear left (southeast) and stop within 100 feet of the road junction for Stop I-1. |

## Stop I-1. Fault Scarp

Approximately 100–200 yards to the northeast is a fault scarp in flows correlated with Wildhorse Butte flows (325±10 ka) having steep, southwest-facing scarps, and displacement to the southwest. Total displacement on the fault ranges from about 5 m to the northwest, gradually decreasing to about 1 m to the southeast. Note that there is a small amount of drag of the upper surface toward the scarp face. This is a remarkably linear feature when viewed on aerial photos. The fault is parallel to the Arco segment of the Lost River range-front fault and to faults in the Box Canyon area of the Big Lost River, which is located about 8 km northeast of this stop (see Kuntz and others, 1994). Kuntz and others (2002) interpreted faults in the Box Canyon area to be of tectonic origin and that represent extensions onto the Snake River Plain of the Lost River range-front fault. A similar origin is postulated for this fault scarp. Smith and others (1989, 1996) and Hackett and Smith (1992) believe the faults in the Box Canyon area are related to dike-emplacement processes. The two different origins for the faults have significant implications for volcanic-hazard and seismic-hazard evaluations for present-day and future reactor and radioactive waste-burial sites at the Idaho National Engineering and Environmental Laboratory.

| Mileage Inc. | Cum. | |
|---|---|---|
| 2.5 | 9.3 | Sixmile Butte shield volcano directly to the left at 9:00 o'clock, vent is 1.5 km away. Vent area for Quaking Aspen Butte shield volcano lies straight ahead, approximately 8 km distant. Wildhorse Butte vent area is approximately 3 km distant in a south-southwest direction (about 1:30 o'clock). |
| 4.6 | 13.9 | Road Junction. Bear straight ahead. Tincup Butte is directly to east (9:00 o'clock), Fingers Butte is to the right at 2:30 o'clock. Sunset Ridge is at 11:00 o'clock. |
| 0.4 | 14.3 | Note steep flow front of pahoehoe flows from Fingers Butte to right. The $^{40}Ar/^{39}Ar$ age of the Fingers Butte lava field is 57±20 ka. The road follows Fingers Butte flows (on right) for about 3 km. |
| 0.8 | 15.1 | Road Junction. Bear right toward "Bear Trap Cave" on sign. |
| 1.1 | 16.2 | Cattle guard. Vent area for Fingers Butte lava field to right at 3:00 o'clock, 1.8 km away. |
| 0.9 | 17.1 | Road to left. Wooden post with no sign marks junction. This road leads to vent area for Quaking Aspen Butte lava field. This road is rough and lined with sagebrush that will scratch vehicle doors. Do not attempt this road without 4WD. |
| 2.1 | 19.2 | Cattle Guard. |
| 0.4 | 19.6 | Stop I-2 is at a high point on the road on the west flank of the Quaking Aspen Butte lava field. At the end of the stop, turn vehicles around and head back north on the Arco-Minidoka road. |

## Stop I-2. Viewscape of the Rock Corral Butte Volcanic Rift Zone and the Southeast Margin of the Craters of the Moon Lava Field

The stop is chosen for its view to the east, south, and west. Many vent areas on the east side of the Craters of the Moon lava field are visible from this spot. From east to south to west, the major vents are:

•**Rock Corral Butte.** A large shield volcano on Rock Corral Butte volcanic rift zone. $^{40}Ar/^{39}Ar$ age of the rock Corral Butte lava field is 55±12 ka.

•**Serviceberry Butte.** A large shield volcano. $^{40}Ar/^{39}Ar$ age of the Serviceberry Butte lava field is 120±12 ka.

•**Split Top Butte.** A large shield volcano. $^{40}Ar/^{39}Ar$ age of the Split Top Butte lava field is 113±10 ka. Most flows from this vent area flow to the east into the Blackfoot 1:100,000-scale quadrangle.

•**Mosby Butte.** A large shield volcano on the southern margin of the Craters of the Moon 1:100,000-scale map. $^{40}Ar/^{39}Ar$ age of the Mosby Butte lava field is 265±30 ka.

•**Horse Butte.** Horse Butte is one of the largest, young shield volcanoes in the area southeast of the Craters of the Moon lava field. It has an awe-inspiring vent that is 1.1-km long, 700-m wide, and 90-m deep. Horse Butte is the source vent for the Bear Trap Cave lava tube-skylight-rootless vent system. Horse Butte flows extend about 35 km north and west from the source vent. The Bear Trap Cave lava-tube system extends about 31 km from Horse Butte, making it the longest lava tube-skylight-rootless vent system in the ESRP.

•**Rattlesnake Butte.** Rattlesnake Butte is a small cinder cone 40-m high that is on the Vent 5149–Rattlesnake Butte eruptive-fissure system. The northwestern part of the eruptive-fissure system is represented by four small, aligned kipukas of cinder deposits that are completely surrounded by the Blue Dragon flows of the Craters of the Moon lava field.

•**Pratt Butte.** A large shield volcano. Only proximal flows are exposed. Medial and distal flows are covered by younger flows. $^{40}Ar/^{39}Ar$ age of the Pratt Butte lava field is 263±20 ka.

•**Blacktail Butte.** This vent area, a fissure-dominated, cinder-cone complex, is the southernmost cinder-cone vent area of the Craters of the Moon lava field. Age of flows from this vent area is about 4,300 $^{14}C$ yr BP.

•**Quaking Aspen Butte.** The vent area for this lava field lies behind (northeast of) the viewpoint about 2 km. Quaking Aspen Butte shield volcano is one of the largest in the ESRP. Quaking Aspen Butte flows have not been dated by $^{40}Ar/^{39}Ar$ methods, but Quaking Aspen Butte flows partly cover the Coyote Butte eruptive-fissure center in the Arco-Big Southern Butte volcanic rift zone, which has been dated at 64±20 ka.

| Mileage Inc. | Cum. | |
|---|---|---|
| 4.3 | 23.9 | Junction. Turn right to “Quaking Aspen Butte airstrip.” |
| 1.3 | 25.2 | Cattle guard. |
| 0.7 | 25.9 | Park for Stop I-3. At the end of the stop, turn vehicles around and head back (west) toward Arco-Minidoka road. |

## Stop I-3. Viewscape of the Arco-Big Southern Butte Volcanic Rift Zone, Big Southern Butte, and Rock Corral Butte Area

The $^{40}Ar/^{39}Ar$ age of Coyote Butte, a fissure-dominated eruptive center, is 64±20 ka, demonstrating that basaltic volcanism is a recent and major process in the Arco-Big Southern Butte volcanic rift zone. Middle Butte and East Butte (hidden behind Middle Butte) are visible on the horizon to the left of Big Southern Butte. Middle Butte has a cap of olivine basalt dated at approximately1 Ma. No rhyolite is exposed on flanks of Middle Butte, but geophysical data suggest that rhyolite forms the core of the Butte. Big Southern Butte consists of two, coalesced cumulo domes. The main, central part of the dome consists of spherulitic, flow-banded rhyolite in the core and autoclastic breccia and sugary rhyolite that represent deformed crust above the flow-banded core. The age of the flow-banded, central part of the dome is 309±10 ka. The flow-banded rhyolitic core uplifted and tilted 45° northeastward a 350-m-thick section of basaltic flows on the northeast flank of the dome. Spear and King (1982) and Fishel (1993) suggest that this section is an uplifted and tilted flap of basalt flows of the predome surface of the ESRP. About 20 individual flows and flow units are present in the flap. Most flows are olivine basalts and evolved olivine basalts; the uppermost flow is ferrolatite from Cedar Butte, which is located out of sight behind and about10 km east of Big Southern Butte. The age of Cedar Butte is 400±19 ka (Kuntz and others, 1994). A massive, aphyric, sugary-textured, curved rhyolite “dike” forms a carapace over the flow-banded rhyolite on the west and southwest sides of the dome. This northwestern part of the dome is dated at 294±15 ka (Kuntz and others, 1994). Big Southern Butte is 6.5 km in diameter, rises 760 m above the surrounding flat surface, and has an exposed volume of about 8 $km^3$. Spear and King (1982) suggest that Big Southern Butte formed in several stages, including initial sill and laccolith stages at depth, followed by extrusion and growth of two endogenous domes on the surface. East Butte, Middle Butte, and Big Southern Butte were prominent landmarks for early travelers and explorers in the ESRP; they were referred to as the “Trois Tetons” and the “Three Buttes” in early descriptions of the area (*e.g.*, Fremont, 1845), whereas the Teton Mountains were referred to as the “Pilot Knobs.” Rock Corral Butte can be observed on the horizon to the south (right) of Big Southern Butte. The $^{40}Ar/^{39}Ar$ age of Rock Corral Butte lava field is 55±12 ka.

| Mileage Inc. | Cum. | |
|---|---|---|
| 2.0 | 27.9 | Junction of Quaking Aspen Butte airstrip road and Arco-Minidoka road. Turn right (north) toward Arco. |
| 15.9 | 43.8 | Junction, Arco-Minidoka Road (3100 E.) and U.S. Highway 20-26. Turn right. |

| | | |
|---|---|---|
| 2.1 | 45.9 | END. Intersection of U.S. Highways 93 and 20-26 at stoplight in downtown Arco, Idaho. |

# Part II: Pre-Holocene Basaltic Volcanism of the Western Part of the Craters of the Moon 30′ x 60′ Quadrangle

| Mileage Inc. | Cum. | |
|---|---|---|
| 0.0 | 0.0 | START. Begin field trip at Texaco station at Adamson's Market (west side) and the Carey Sport Shop (east side) of U.S. Highway 20-26 in downtown Carey, Idaho. |
| 0.7 | 0.7 | Park in lot on right just past the Loading Chute Restaurant for Stop II-1. |

## Stop II-1. Fault in Basalt At Carey

Across road on northwest side is a fault in basalt at Carey. $^{40}Ar/^{39}Ar$ age of flow is 4.20±0.02 Ma. The scarp at the road level is about 7-m high; about 1.5 km northwest, the scarp is about 10-m high. Note that basalt flow dips about 2° to the southeast, toward the Snake River Plain.

| Mileage Inc. | Cum. | |
|---|---|---|
| 1.1 | 1.8 | Carey Lake on right (south). Lake formed by damming of springs that lie just north of road by Carey flows of the Craters of the Moon lava field (radiocarbon age 12,010±150 $^{14}C$ yr BP; table 1). |
| 0.7 | 2.5 | Shield volcano on horizon at 1:00 o'clock is Laidlaw Butte. Laidlaw Butte is one of the highest shield volcanoes on the ESRP, rising about 275 m above surrounding, younger flows. Flows of this shield are characterized by extremely coarse texture containing plagioclase crystals as long as 3 cm. The relatively high viscosity of the lava probably caused "piling up" of flows near the vent and creation of steep shield flanks. |
| 3.1 | 5.6 | Gravel pits are in alluvial fan deposits of Fish Creek. Alluvial deposits lie on flows of the Fish Creek Reservoir lava field. Vent for flows is at Fish Creek Reservoir and lies about 8 km north of highway. |
| 1.5 | 7.1 | Turn right (south) on Carey-Kimama road (Laidlaw Park road). Fish Creek Reservoir flows on right. |
| 0.2 | 7.3 | Gravel pits on left are in alluvial-fan deposit of Fish Creek. |
| 1.0 | 8.3 | Intersection. Interpretive kiosk is for Craters of the Moon National Monument. Turn left (east). |
| 0.1 | 8.4 | Road rises onto loess-covered pahoehoe (Hawaiian term for basaltic lava flow having billowy, ropy surfaces) flow of unknown age and unknown source vent. Source vent probably east of this point. |
| 0.7 | 9.1 | Road curves to right and rises onto pahoehoe of the Carey flows of the Craters of the Moon lava field (radiocarbon age 12,010±150 $^{14}C$ yr BP; table 1). Contrast lack of loess cover on Carey flows here with flows observed 0.7 km back to west. |
| 0.4 | 9.5 | Collapse pits in Carey pahoehoe flows to left and right of road. |
| 0.8 | 10.3 | Road drops off Carey flows onto older flows in Paddelford Flat. Paddelford Flat is a kipuka surrounded by flows of the Craters of the Moon lava field. Note that flows here are loess covered and very smooth. Excavation site for radiocarbon samples for dating Carey flows lies about 10 m north of road at this location. |
| 1.0 | 11.3 | Road intersection. Turn right (south) onto Carey-Kimama road. |
| 0.5 | 11.8 | Road rises onto pre-Holocene pahoehoe flows in south part of Paddelford Flat. Even though pre-Holocene, these flows are very young, probably 40–20 ka. |
| 0.6 | 12.4 | Flow fronts for pahoehoe flows from here and for several kilometers. |
| 3.9 | 16.3 | Road rises onto north edge of Carey flow. |
| 0.8 | 17.1 | South edge of Carey pahoehoe flows. Wagon Butte to right at 2:00 o'clock. $^{40}Ar/^{39}Ar$ age of Wagon Butte is 120±25 ka. Laidlaw Butte shield volcano to left at 10:00 o'clock. $^{40}Ar/^{39}Ar$ age of Laidlaw Butte lava field is 425±25 ka. |

Table 1. Radiocarbon ages of lava flows in the Craters of the Moon and Quaking Aspen Butte lava fields of the eastern Snake River Plain, Idaho.

[Type of sample: sa = charred sediment pretreated by sieving and acid leaching only; sdda = charred sediment pretreated by dissaggregation-deflocculation-acid method; saaa = charred sediment pretreated by sdda method and by acid-alkali-acit pretreatment; ca = charcoal leached with dilute HCI acid only; caaa = charcoal pretreated by acid-alkali-acid method. For lab number, prefit Tx refers to University of Texas (Valastro and others, 1972); prefix W refers to samples analyzed at the USGS Radiocarbon Laboratory, Reston, Va. Prefix USGS refers to samples analyzed at the USGS Radiocarbon Laboratory, Menlo Park, Calif. Radiocarbon measurements were made by the standard acetylene gas counting method at the USGS Radiocarbon Laboratories, Reston, Va., and Menlo Park, Calif. Sample activities were not corrected for isotope fractionation by a $^{13}C$ measurement. The ages were calculated relative to the U.S. National Bureau of standards oxalic acid standard activity (Stuiver and Polach, 1977). See Kuntz and others (1986) for details of radiocarbon dating methods and data.]

| Lava fields, lava flows, and eruptive periods | Sample pretreatment | Field number | Lab number or reference | $^{14}C$ date (yr B.P.) | Mean or oldest age (yr B.P.) |
|---|---|---|---|---|---|
| | | CRATERS OF THE MOON LAVA FIELD | | | |
| **Eruptive period A** | | | | | |
| Broken Top | | | | Undated | |
| Blue Dragon | ca | K79-C5 | W-4466 | 1,670±60 | |
| | caaa | K79-C5 | W-4578 | 2,030±80 | |
| | caaa | | Tx-899 | 2,110±90 | |
| | caaa | | Tx-900 | 2,050±80 | 2,076±45 |
| | caaa | | Tx-901 | 2,200±130 | |
| Trench Mortar Flat | caaa | | Tx-1157 | 2,210±80 | |
| | caaa | | Tx-1158 | 2,240±80 | |
| | caaa | | Tx-1159 | 2,250±80 | |
| | caaa | | Tx-1160 | 2,310±70 | 2,205±25 |
| | caaa | | Tx-1161 | 2,130±80 | |
| | caaa | | Tx-1162 | 2,270±80 | |
| | caaa | | Tx-1163 | 2,140±60 | |
| | ca | K79-C3 | W-4413 | 2,100±60 | |
| | caaa | K79-C6 | W-4581 | 2,180±70 | |
| North Crater | | | | Undated | |
| Big Craters | ca | K80-C1 | W-5342 | 2,400±300 | 2,400±300 |
| Serrate | | | | Undated | |
| Devils Orchard | | | | Undated | |
| Highway | | | | Undated | |
| Eruptive period B | | | | | |
| Vermillion Chasm | | | | Undated | |
| Deadhorse | sdda | K78-S55 | W-4259 | 4,300±60 | 4,300±60 |
| Devils Cauldron | sdda | K78-S56 | W-4287 | 2,820±90 | |
| | saaa | K78-S56 | W-4339 | 3,660±60 | 3,660±60 |
| Minidoka | sdda | K78-S58b | W-4267 | 2,650±50 | |
| | saaa | K78-C7 | W-4447 | 3,510±100 | 4,510±100 |
| Black Top | | | | Undated | |
| Eruptive period C | | | | | |
| Indian Wells north | | | | Undated | |
| Indian Wells south | | | | Undated | |
| Sawtooth | saaa | K78-S67 | W-4370 | 6,020±160 | 6,020±160 |
| South Echo | | | | Undated | |
| Sheep Trail Butte | | | | Undated | |
| Fissure Butte | | | | Undated | |

Table 1. Radiocarbon ages of lava flows in the Craters of the Moon and Quaking Aspen Butte lava fields of the eastern Sna
Plain, Idaho.—Continued

| Lava fields, lava flows, and eruptive periods | Sample pretreatment | Field number | Lab number or reference | $^{14}$C date (yr B.P.) | Mean or olde (yr B.P.) |
|---|---|---|---|---|---|
| Sentinel | | | | Undated | |
| **Eruptive period D** | | | | | |
| Silent Cone | | | | Undated | |
| Carey Kipuka | sdda | K78-S64 | W-4310 | 3,860±120 | |
| | saga | K78-S64 | W-4592 | 6,600±60 | 6,600±60 |
| Little Park | sdda | K78-S66 | W-4260 | 3,960±90 | |
| | saga | K78-S66 | W-4587 | 6,500±60 | 6,500±60 |
| Little Laidlaw Park | | | | Undated | |
| **Eurptive period E** | | | | | |
| Grassy Cone | saga | K78-S60 | W-4385 | 6,670±100 | |
| | saga | K79-C12 | W-4488 | 7,360±60 | 7,360±60 |
| Laidlaw Lake | saaa | K79-C9 | W-4511 | 7,470±80 | 7,470±80 |
| Lava Point | saaa | K78-S68 | W-4497 | 7,840±140 | 7,840±140 |
| **Eruptive period F** | | | | | |
| Pronghorn | sdda | K78-S73 | W-4271 | 6,820±60 | |
| | saga | K78-S73 | W-4586 | 10,240±120 | 10,240±120 |
| Bottleneck Lake | sdda | K78-S72 | W-4291 | 5,230±110 | |
| | saaa | K78-S72 | W-4343 | 7,900±100 | |
| | sdda | K78-S71 | W-4280 | 9,330±120 | |
| | sdda | K78-S71 | W-4305 | 11,000±100 | 11,000±100 |
| Heifer Reservoir | sdda | K78-S53b | W-4306 | 9,330±120 | |
| | saaa | K78-S54 | W-4583 | 10,670±150 | 10,670±150 |
| **Eruptive period G** | | | | | |
| Sunset | sdda | K78-S58c | W-4270 | 3,270±80 | |
| | sdda | K76-C4A | W-3674 | 11,120±120 | |
| | ca | K78-S77 | W-4296 | 12,010±150 | 12,010±150 |
| Carey | sdda | K78-S62 | W-4235 | 4,310±80 | |
| | sdda | K78-S61c | W-4301 | 6,500±110 | (-12,000) |
| Lava Creek | saaa | K79-C11 | W-4478 | 11,970±120 | |
| | saaa | K79-C10 | W-4476 | 12,760±150 | 12,760±150 |
| **Eruptive period H** | | | | | |
| Kimama | saaa | K78-S75 | W-4387 | 13,900±400 | |
| | saaa | K79-C8 | W-4473 | 15,100±160 | 15,100±160 |
| Bear Den Lake | | | | Undated | |
| Baseline | | | | Undated | |
| Little Prarie | | | | Undated | |
| Lost Kipuka | | | | Undated | |
| No Name | | | | Undated | |
| Brown Flow | | | | Undated | |
| QUAKING ASPEN BUTTE LAVA FIELD | | | | | |
| Quaking Aspen Butte | sa | K77-C5 | W-3918 | >40,000 | >40,000 |

| | | |
|---|---|---|
| 2.6 | 19.7 | Sign “Leaving National Monument.” |
| 0.3 | 20.0 | Enter flows of Spud Butte-Broken Top Butte flow complex. $^{40}Ar/^{39}Ar$ age of Broken Top lava field is 57±30 ka. |
| 3.2 | 23.2 | Drop into 300-m-wide lava channel, having leveed walls as high as 10 m. This channel extends 2.5 km north, west, and south from main vent at “The Blow Out” lava field. A rafted block has been stranded in the channel to the left (east). |
| 0.3 | 23.5 | Note levees on south side of channel. |
| 0.9 | 24.4 | Turn onto dirt road on left. Travel 0.1 mi and stop. Do not travel 0.2 mi! |
| 0.1 | 24.5 | Following Stop II-2, return 0.1 mile to main road (Carey-Kimama road), turn right (north), and retrace route north for about 13.0 mi to the intersection of the Laidlaw Park and Carey-Kimama roads in Paddelford Flat. |

## Stop II-2. Vent Area for “The Blow Out”

Broad, low area directly east is a lava lake. Note walls of lake are 20- to 25-m high. The walls of the lava lake are made up of thin layers of shelly pahoehoe. Note the local frothy character of these flows and that individual flows are made up of interlayered dense and vesicular flow units. These variably-textured flow units represent different conditions of overflow of the lava lake: dense layers represent overflow or explosion of degassed lava from lake, vesicular layers represent overflow of more gas-charged lava. A 100-m-wide, 4.3-km-long lava channel extends east-southeast of the southern end of the lava lake. At the left (north end) of the lava lake is the main vent for “The Blow Out.” This vent is a circular depression, 70-m deep and 300-m wide. The $^{40}Ar/^{39}Ar$ age of “The Blow Out” lava field is 116±15 ka. Looking *south* from this location, note Vent 4792 shield volcano at about 5:30 o’clock, about 3 km distant, and Wildhorse Butte ($^{40}Ar/^{39}Ar$ age <50 ka) shield volcano at about 6:00 o’clock (due south), about 10 km distant. In looking *west* from this location, note Sand Butte (tephra cone), Broken Top, and Spud Butte (from left to right; south to north) on the horizon. The vents for these three lava fields are aligned along a 15-km-long, north/south-trending, eruptive-fissure system. These three lava fields have the same paleomagnetic directions, which strongly suggest that they formed contemporaneously. The age for one of these lava fields, the Broken Top field, is 57±30 ka, thus this volcanic rift zone was active at about 60 ka. Sand Butte is a circular tephra cone about 1,400 m in diameter. The cone has a north-south elongated depression about 700 m in diameter; the cone walls are about 100-m high. The cone consists of well-bedded, locally agglutinated ash and palagonitized sideromelane deposited by hydrovolcanic eruptions during the later stages of volcanic activity at Sand Butte. In looking due *north* from this location, note foothills of the Pioneer Mountains, then, progressively to the right (south) are cinder cones (including Grassy, Sunset, Big Craters, Big Cinder Butte, among others) of the northern part of the Craters of the Moon lava field and the Great Rift volcanic rift zone, Laidlaw Butte (large shield volcano), Big Southern Butte, and Bear Den Butte (the cinder cone for the Bear Den Butte lava field. The $^{40}Ar/^{39}Ar$ age of Bear Den Butte lava field is 58±10 ka.

| Mileage Inc. | Cum. | |
|---|---|---|
| 13.0 | 37.5 | Junction. Laidlaw Park and Carey-Kimama roads. Turn right (east). Vents that caused diversion of Carey flows and created Paddelford Flat kipuka are at 11:00 o’clock, about 3 km distant. |
| 1.6 | 39.1 | Tongue of Carey pahoehoe to left (north), about 1 km away. |
| 0.4 | 39.5 | Channel in Paddelford Flat flows. |
| 0.2 | 39.7 | Road rises onto Grassy Cone rough-surfaced pahoehoe flow. This is not an a' a (Hawaiian term for basaltic lava flows typified by rough, jagged, clinkery, spinose surface) flow. Surface roughness here is due to collapse of pahoehoe-flow surfaces. Note that plates consist of broken, ropy pahoehoe. Age of Grassy Cone flows is 7,360±60 $^{14}C$ yr BP (table 1). |
| 0.5 | 40.2 | Big Cinder Butte in Craters of the Moon lava field at 11:30 o’clock on the horizon. |
| 0.9 | 41.1 | Kipuka in Grassy Cone pahoehoe flows. |
| 1.1 | 42.2 | Road drops off Grassy Cone flows into Little Park, another of the large kipukas on the west side of the Craters of the Moon lava field. Vents for Little Park pahoehoe flows are at 10:00 o’clock to left (north). |
| 1.2 | 43.4 | Channel in pahoehoe flows of Little Park. |
| 2.1 | 45.5 | Road ascends steep flow front of Little Park a' a flow. This is the first of several true a' a flows in the Little Park-Laidlaw Park area that are encountered on or near the Laidlaw Park road. Age of Little Park a' a flow is 6,500±60 $^{14}C$ yr BP (table 1). |
| 0.3 | 45.8 | Park for Stop II-3. |

## Stop II-3. Little Park A' A Flow

This stop provides the easiest access to an a' a flow of the Craters of the Moon lava field. In the Craters of the Moon lava field, pahoehoe flows have a typical partial chemical composition as that given for the Carey flow, and a' a flows have compositions similar to or slightly more silicic than the Little Park a' a flow. Partial chemical analyses (in percent) for Carey pahoehoe flow and Little Park a' a flow are given below:

| | Carey pahoehoe | Little Park a' a |
|---|---|---|
| $SiO_2$ | 47.22 | 49.46 |
| $Al_2 0_3$ | 13.46 | 14.28 |
| $Fe_2O_3$ | 0.89 | 1.14 |
| FeO | 14.93 | 13.55 |
| MgO | 3.91 | 3.08 |
| CaO | 8.24 | 6.49 |
| $Na_2O$ | 3.47 | 4.28 |
| $K_2O$ | 1.94 | 2.30 |

Note the very slight, but significant differences in the compositions of the two flows that lead to such marked differences in flow type. There is only a 2 percent difference in silica, total iron is about the same, lime is significantly lower in the a' a flow, magnesia is slightly lower in the a' a flow, and the total alkalis are approximately equal. Evidently, the slightly higher silica and lower magnesia and lime must have a pronounced effect to increase the viscosity of the a' a lavas.

At this locality, examine the character of the a' a flows. Look for spiny fragments of lava, accretionary lava balls, and note the density of fragments. Most a' a flows contain prominent flow ridges that are perpendicular to and convex toward the direction of flow movement, much like the ogives that characterize the surfaces of glaciers. A' a flows also contain longitudinal furrows and cracks that are roughly parallel to the direction of flow movement. These furrows and cracks are the surface expression of vertical or near vertical shear planes that separate the a' a flow into longitudinal lobes that moved at different rates with respect to one another. The flow ridges and furrows/cracks may not be visible from ground level, but they are obvious on air photos. It is extremely difficult to walk on a' a flows. Be careful!

| Mileage Inc. | Cum. | |
|---|---|---|
| 0.3 | 46.1 | Drop down steep flow front of Little Park a' a flow and cross cattle guard. Road enters Laidlaw Park. |
| 2.6 | 48.7 | Ant Butte Junction. Turn left (north). |
| 0.1 | 48.8 | Cattle guard. Bear right. |
| 1.0 | 49.8 | Ant Butte cinder cone ahead on left. Ant Butte is local source of cinders for road aggregate. |
| 1.6 | 51.4 | Big Blowout Butte on left. Road passes through neck of lava lake that extends southeast from vent crater for distance of about 1 km. $^{40}Ar/^{39}Ar$ age of Big Blowout Butte lava field is 210±15 ka. |
| 1.8 | 53.2 | Road crosses eruptive fissure for Hollow Top lava field. Vent is difficult to discern at road level but is obvious on air photos. Hollow Top is undated. |
| 0.4 | 53.6 | Landing strip to left. |
| 1.0 | 54.6 | Note steep flow fronts for Little Park and Indian Wells South a' a flows to left (north) of road about 0.8 km distant. Road begins relatively steep ascent of west flank of Snowdrift Crater shield volcano. Note the very smooth character of flows that make up west flank of Snowdrift Crater shield volcano, due largely to a significantly thick (~1–3 m) mantle of loess and eolian sand. If the road is dry, you will notice the loess as it fills the air behind vehicles ahead. Be sure to roll up windows. |
| 1.6 | 56.2 | Dirt road on left. Turn left, go 0.1 mi. Do not go 0.2 mi! |
| 0.1 | 56.3 | Following Stop II-4, turn vehicles around and retrace route back across Laidlaw Park, Little Park, Paddelford Flat and the Carey pahoehoe flow to the junction of the Carey-Kimama/Laidlaw Park road and U.S. Highway 20-26. |

## Stop II-4. Snowdrift Crater

Snowdrift Crater is the vent for the Snowdrift Crater shield volcano. This shield rises about 90 m above surrounding, younger flows on the west. The vent area is a N. 45° W.-trending depression 1,500-m long, that consists of two craters: northwestern crater is circular and 35-m deep and southeastern crater is elongated and 55-m deep. Crater walls consist of well-layered shelly pahoehoe. The $^{40}Ar/^{39}Ar$ age of Snowdrift Crater lava field is 480±50 ka. Little Laidlaw Park a' a flows of the Craters of the Moon lava field lap up onto the east flank of Snowdrift Crater to within 25 m of summit. Because of its height, Snowdrift Crater shield volcano formed a significant edifice that impeded the southward movement of a' a flows of eruptive periods C and D of the Craters of the Moon lava field and created the large kipuka known as Laidlaw Park. From this locality, large cinder cone on horizon directly north, about 6 km distant, is Big Cinder Butte, the source vent for Indian Wells North, Indian Wells South, and Sawtooth a' a flows. To the northeast (about 1:30 o'clock) is North Laidlaw Butte, about 2 km distant. North Laidlaw Butte is a kipuka cinder cone that is completely surrounded by Indian Wells North and Sawtooth a' a flows. North Laidlaw Butte is relatively old, as shown by its significant cover of loess.

| Mileage Inc. | Cum. | |
|---|---|---|
| 22.7 | 79.0 | Junction, Carey-Kimama/Laidlaw Park road and Highway 20-26. Turn left (west) on U.S. Highway 20-26 to return to Carey. Turn right (east) on U.S. Highway 20-26 to return to Visitor Center at Craters of the Moon National Monument and/or Arco, Idaho. |

## Part III. Craters of the Moon Lava Field and the Northern Part of the Great Rift Volcanic Rift Zone

### Introduction to the Developed Portion of the Craters of the Moon National Monument and Preserve

Craters of the Moon National Monument was originally set aside by President Calvin Coolidge in 1924 to preserve, for both present and future generations, what was described as "a weird and scenic landscape peculiar to itself." On November 9, 2000, President Bill Clinton increased the size of the original Monument 13-fold and assigned joint management of the expanded Monument to the National Park Service and the Bureau of Land Management. As a result, approximately 750,000 acres (1,100 mi$^2$) of the area surrounding the Great Rift has been withdrawn from extractive operations (with the exception of existing authorized materials sites within the Monument) and limits mechanized travel within the Monument to roads. Outside the Monument, rock collecting and other extractive operations are permitted, and travel is not as restricted. Almost all of the Great Rift volcanic rift zone, which is the best-developed example of a volcanic rift zone on the ESRP, lies within the Monument. Of the eight geologically young lava fields found on the ESRP, the Monument encompasses the three youngest. Therefore, these three lava fields are some of the least altered by natural processes, making them some the best places for observing geologic features associated with basaltic volcanism on the ESRP. The Monument now includes all but the northern-most part of the Craters of the Moon (COM) lava field, the largest, dominantly Holocene basaltic lava field in the lower 48 states. Monument designation thus provides a long-term beneficial impact to ESRP geologic resources by not only protecting and preserving a sizeable part of the ESRP geology for future generations to enjoy, but also by preserving and protecting some of the best geologic examples of basaltic volcanism within the continental United States.

| Mileage Inc. | Cum. | |
|---|---|---|
| 0.0 | 0.0 | **STOP III-1. CRATERS OF THE MOON VISITOR CENTER.** When you arrive at the Visitor Center, take a few minutes to look at the exhibits and use the restrooms. Road log will follow route on figure III-1. |

LUNCH: Maintenance Shop. We will be using the woodshop in the maintenance building behind the Visitor Center for lunch while viewing animations that help explain some of the geology within the developed part of the Monument. These animations are being created by Idaho BLM staff (Antonia Hedrick, Cooper Brossy, and Sara C. Smith) in collaboration with the Educational Multimedia Visualization Center, Dr. Tanya Atwater's animation laboratory at University of California at Santa Barbara.

Trip leaders will be on hand to answer questions during lunch. A 20-page general overview of the Monument geology will be passed out at lunch, along with a 10-page description of the recent rafted-block investigation.

| Mileage Inc. | Cum. | |
|---|---|---|
| 0.2 | 0.2 | Entrance Station. |
| 0.2 | 0.4 | Entrance to Campground. The block-a' a trachyandesite flow in the campground is one of the most silica-rich flows (63 percent silica) of the COM lava field, and it is considered to be part of the undated Highway flow (table 1). The Highway flow will be discussed at Stop III-2. |
| 0.3 | 0.7 | Turnout on right for North Crater flow interpretive trail. Continue on loop road. |
| 0.1 | 0.8 | Park at turnout for Stop III-2. |

### Stop III-2. Turnout Located at East Flank of North Crater

This trailhead is the start of the North Crater-to-Spatter Cones trail. We will be hiking a few hundred meters on this steep cinder trail to a good overlook of the area. Binoculars and/or cameras with a telephoto lens will be an advantage. A brief discussion of the pressure or flow ridge to the north and its attendant examples of squeeze-ups will be contrasted to

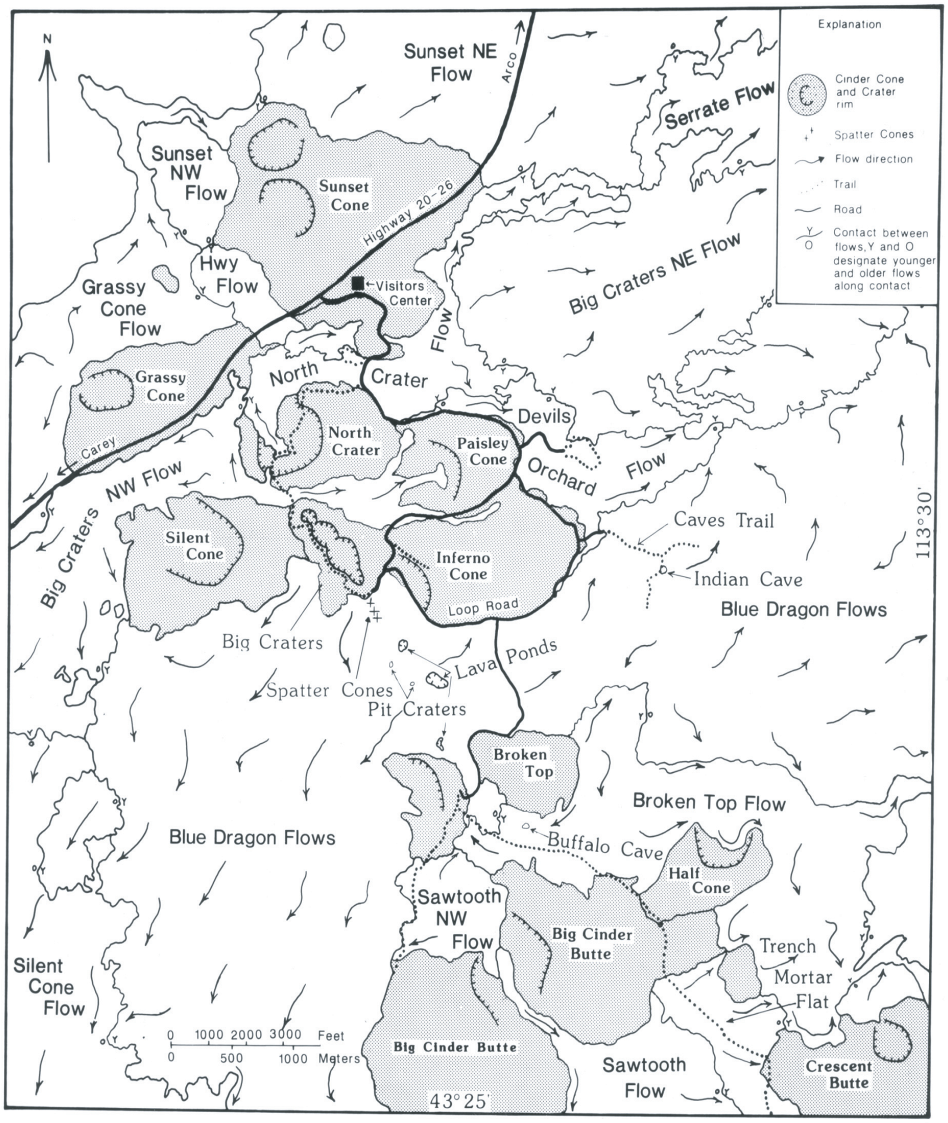


Figure III-1. Area around Craters of the Moon Loop Drive.

other similar features in other parts of the Monument. The trail continues for about 2 km to where it joins the paved trail at the south rim of Big Craters cinder-cone complex.

## Stop III-3. Geologic Features at North Crater and Vicinity

Look to the north and notice the sharp drop-off just below the campground, this is the "Highway fault." You can trace the fault off into the distance to the west. The very jagged lava flow nestled between Sunset Cone and Grassy Cone is the Highway flow (fig. III-1). The blocky lava flow that the campground is built on also is a part of this flow. The Highway fault likely represents a collapse scarp that formed because of the large volume of lava that was poured out from the magma chamber (possibly beneath ancestral North Crater cinder cone) in a series of flows. The hill north of the North Crater Flow Trail parking area is either a remnant of North Crater, a very large rafted block, or possibly a part of another old cone.

The area around North Crater cinder cone and the Visitor Center is one of the more complex areas in the Craters of the Moon lava field, and the North Crater Trail provides a good vantage point to view this area. About 2,300 yr ago, this area may have looked very different than it does today. Specifically, North Crater and the small flank cone behind the fee/entrance booth on the southeast side of Sunset Cone probably were larger, and another cone or cones may have existed to the north of North Crater (see fig. III-2). Five lava flows, the Highway, Devils Orchard, Serrate, Big Craters Northeast, and North Crater flows, erupted from vents in the area (see fig. III-3). Three of these flows, the Highway, Devils Orchard, and Serrate flows, are particularly high in silica, 54–64 weight percent (Kuntz and others, 1986). They erupted violently and were viscous enough to break apart cinder cones and carry the pieces as far as 13 km to the northeast (see fig. III-3). These pieces of broken cinder cones, carried by lava flows like icebergs in ocean currents, are termed "rafted blocks." As rafted blocks were carried by lava flows, they broke up into smaller pieces and became incorporated into the transporting flow. Later, younger flows buried many of them. Only the largest and most coherent blocks, which poke through the younger lava flows, are easily seen (see fig. III-4 for distribution of rafted blocks). The North Crater Flow Trail and Devils Orchard Nature Trail provide excellent closeup views of rafted blocks, while the viewpoint atop Inferno Cone offers a panorama of the tremendous scale and extent of rafted blocks.

For a more in-depth discussion of the existence of now absent (destroyed?) cinder cones, the duration and timing of the lava flows, and the process of block rafting, consult the handout from lunch or see *The North Crater Neighborhood—More complex than Mr. Rogers'* on the Monument web site: *http://data2.itc.nps.gov/nature/documents/field%5Ftrip%5Ftext%5F2%2D1%2Epdf.*

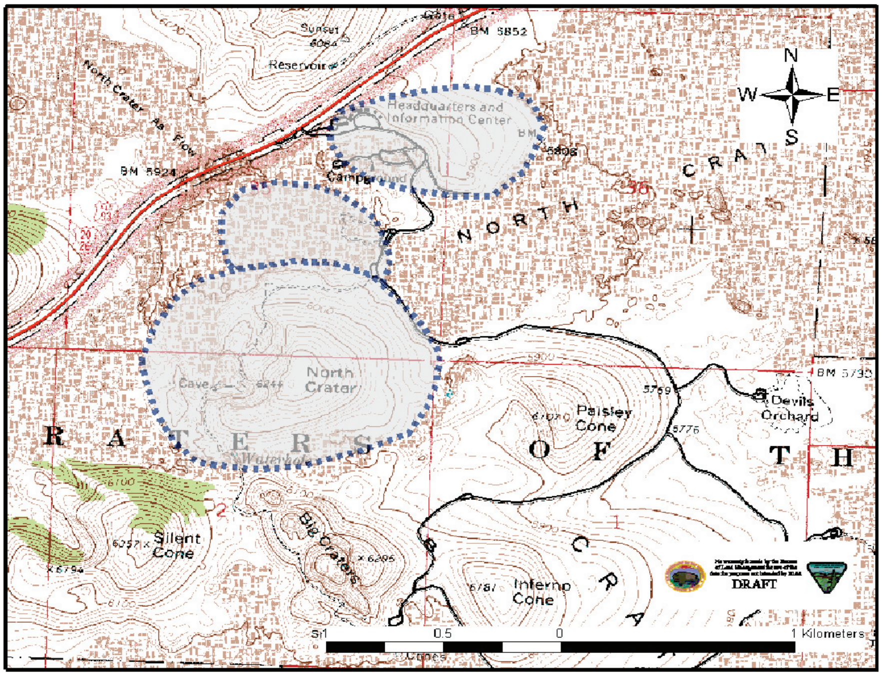


Figure III-2. Portion of Inferno Cone USGS 7.5 minute topographic quadrangle showing the extent and location of present-day North Crater, a possible paleo-North Crater and possible cousins of North Crater prior to block rafting events.

Reconstruction of North Crater by adding the volume of material rafted from the North Crater area to the current North Crater creates a paleo-North Crater that is much larger than present-day North Crater. At minimum, the volume of rafted material is $46x10^6$ $m^3$. The volume of the breach in North Crater is only $1.2x10^6$ $m^3$. Adding the rafted material ($46x10^6$ $m^3$) to the current North Crater ($42x10^6$ $m^3$) suggests paleo-North Crater may have been as large as $88x10^6$ $m^3$. The radius and height of this large paleo-North Crater would have been, respectively, nearly 200 m greater in diameter and 40 m higher than the modern North Crater. It would have extended from North Crater's current position north to U.S. Highway 20/26/93 and east to the campground. Since the North Crater area has had a prolonged and complex eruptive history, it is possible that several smaller paleo-North Craters existed through time, each being built, partially or completely destroyed by explosive events, and then rebuilt.

If you proceed along the North Crater trail between 1.3 and 1.6 km, you will have the opportunity to see some of the xenoliths associated with North Crater. The most common type of xenolith is composed of pumiceous glass that stands out in stark contrast to the basalt because of its whitish color. The pumice may be related to the rhyolitic rocks formed during eruptions that occurred on the ESRP prior to basaltic volcanism, to Eocene-age rocks of the Challis Volcanic Group, to Mississippian sedimentary rocks, or to Tertiary intrusive rocks. Less common are granulitic xenoliths, thought to represent material from the cratonic basement. Least common are xenoliths from Eocene Challis volcanic rocks.

At about 1 km from the trailhead, the trail climbs steeply up from the North Crater pahoehoe flow in the most recently active vent area for North Crater. Watch for boulders of very dense glass-like basalt. This material is tachylyte, the basaltic equivalent of obsidian.

At approximately 2.9 km, you will pass by an eruptive fissure on your left, which looks like a deep, elongate trench. This fissure is one of the eruptive centers for the Big Craters

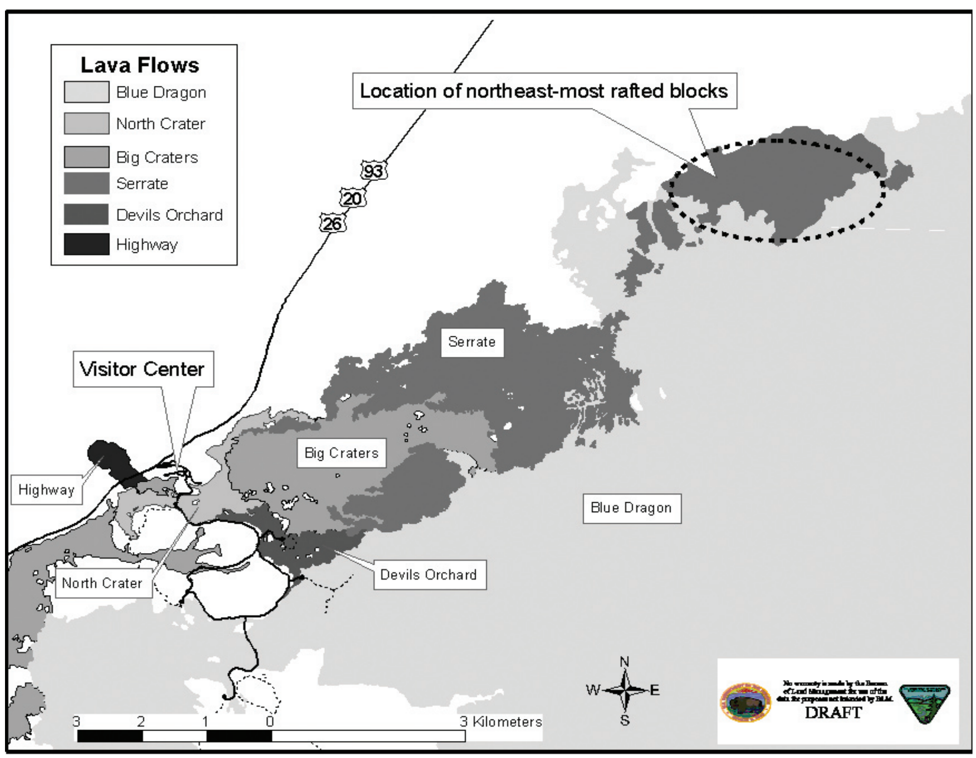


Figure III-3. Map showing extent of lava flows and the location of northeastern most rafted blocks.

flow of eruptive period A. Just beyond the eruptive fissure, the trail begins to climb Big Craters, which consists of at least nine nested cones that indicate a complicated eruptive history. Please watch your footing as you peer into the cones.

**End of Stop III-2. Return to vans. Continue on loop road.**

| Mileage Inc. | Cum. | |
|---|---|---|
| 0.4 | 1.2 | Big Craters flow to right mantles the western flank of Paisley Cone. The fissure vents for these pahoehoe hawaiite flows are located between North Crater and Big Craters and on the north flank of Big Craters. For the next 2 km, the loop road follows the north, east, and south flanks of Paisley Cone, assumed to have an age of about 6 ka (see table 1). |
| 0.2 | 1.4 | Devils Orchard flow on left. This heavily cinder-covered, block-a' a trachyandesite flow was thought by early workers to be quite old. However, it correlates with the Highway and Serrate flows, approximately 2.3 ka (table 1). The Serrate, Devils Orchard, and Highway flows are considered to be about 2,300 yr based on stratigraphic and paleomagnetic data (see table 1). |
| 0.4 | 1.8 | Entrance to Devils Orchard Interpretive Trail on left. Continue on loop road. |
| 0.1 | 1.9 | Intersection with one-way loop drive. Bear right. |
| 0.2 | 2.1 | Tongue of Big Craters flow. Looking left in the valley between Paisley Cone (on right) and Inferno Cone (on left) is a small lobe of the Big Craters flow. Inferno Cone is directly south on the left. Big Craters area is west (straight ahead), and North Crater is to north (on the right, see fig. III-1). |

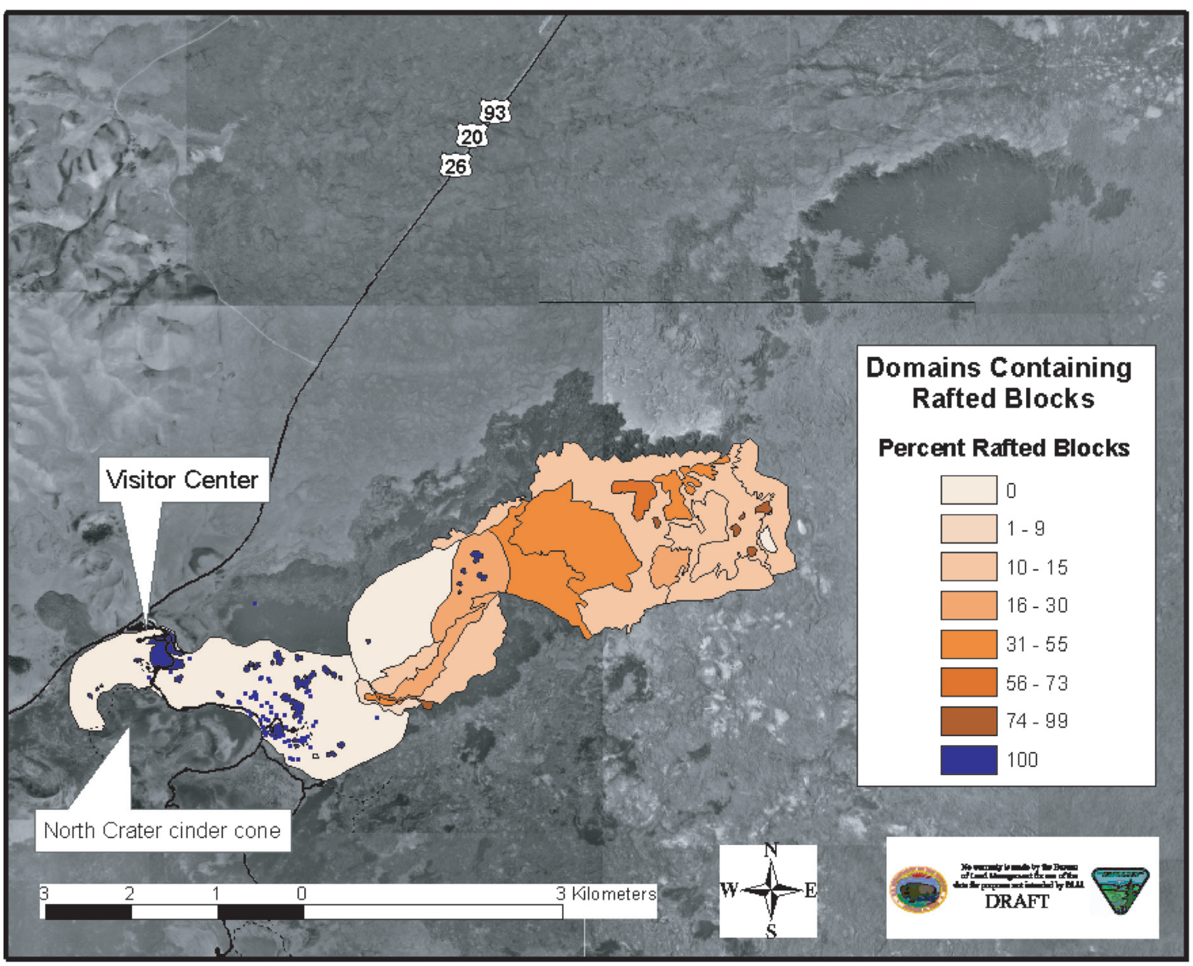


Figure III-4. Digital air photo showing locations of domains of rafted material.

0.6 2.7 Turnout to Inferno Cone parking lot. Inferno Cone is undated, but assumed to be about 6 ka (see table 1). Although not a stop for this road log, visitors may want to hike the trail to the top of Inferno Cone. At the top of Inferno Cone, facing north, geographic features to be noted, in a clockwise direction, are: 9:30 to 10:00 o'clock, Big Craters nested cinder cone complex; 10:30 o'clock, Grassy Cone; 11:00 o'clock, North Crater; 12:00 o'clock, Sunset Cone (directly behind the Visitor Center with the Pioneer Mountains in the far background); and 1:00 o'clock, Paisley Cone. The profile against the mountains of the vegetated surface of the Sunset flow is visible beyond Paisley Cone. On the near side of the Sunset flow is the Serrate flow that extends to the east (right) as far as Round Knoll, a grass-covered kipuka (at 2:30 o'clock) of older Snake River Plain lava flows and cinders**.** The very large butte to the east is Big Southern Butte. To the left of Big Southern Butte are East (left) and Middle (right) Buttes that appear to be one butte from this perspective. Low shield volcanoes are clearly visible to the left and right of the buttes. The eastern part of the vast Blue Dragon flow is in the foreground.

To the southwest is a big cinder cone, called Big Cinder Butte, which is the largest cinder cone in the Monument. At 11:00 o'clock, the two easternmost cinder cones in this direction are Half Cone in the foreground and Crescent Butte, with its distinctive crescent shape. In the background is the dark, saddle-shaped cone, Blacktop Butte, the most southerly cone along the northern part of the Great Rift, and about 20 km away. Many of the more than 25 cinder cones in the COM lava field can be seen from this vantage point, but they are too numerous and closely spaced to differentiate.

From the southwest rim, one may observe the vent and "plumbing system" responsible for the eruption of the vast eastern lobe of the Blue Dragon flow, the largest of all flows of eruptive period A. The "plumbing system" consists of an eruptive fissure, located in the southern part of Spatter Cones–Big Craters area, pit craters, such as Crystal Pit, that overlie the southern end of the eruptive fissures; perched lava ponds, such as Big Sink, that are located on the upper part of a lava tube system that extends east and south of the eruptive fissure; and a lava-tube system that contains numerous skylight entrances into the tubes (Cave area, see fig. III-1). Farther east are rootless vents or hornitos, where lava moving through the tube system was extruded through openings in tube ceilings. Also visible directly south, beyond Big Sink and Lava Cascades, is Broken Top cinder cone and the area to be visited in Stop III-3. Several 2.1-ka fissures slice across the northeast and southwest sides of Broken Top. Source vents for the youngest flow in the COM lava field, the Broken Top lava flow, are on the eruptive fissure on the east and northeast flanks of Broken Top.

0.2 2.9 Spatter Cones-Big Craters Area. At this area, one can view the eruptive features and vent areas along a part of the Great Rift that was active about 2.1 ka, producing the Blue Dragon flow. A segment of the Great Rift about 10-km long that extends from North Crater southeast to the Watchman cinder cone (fig. III-1) was active at various times during the latest eruptive period of the COM lava field. The vents in the area produced about 3.5 km$^3$ of lava that now covers about 20 percent of the COM lava field. At about the same time, a rift segment of comparable length was active and formed the Kings Bowl and Wapi lava fields in the southern part of the Monument. The Spatter Cones formed in the waning activity along a short, 1-km-long eruptive fissure that extends southeast from the south end of Big Craters. Most of the lava that forms the extensive Blue Dragon flow was erupted from the Great Rift in the Spatter Cones-Big Craters area. Take the trail to the west that ascends to the southern end of Big Craters. Big Craters is a nested cinder cone complex that contains at least nine cones. On the southwest rim, agglutinated spatter material mantles the inner wall of the south-southeast parts of the complex. The mantle drapes over the rim of the complex and covers the outer wall. About 100 m north along the trail, remnants of a lava lake lie along the north wall of the inner crater. Just south of the lava lake remnant, the crest of a small cinder cone has a red streak aligned parallel to the eruptive fissure. Late-stage corrosive steam from the fissure oxidized the black cinders. Lava issued from several satellite vents at the base of Big Craters flow complex along its western (left) flank and traveled to the southwest. Additional nested craters are viewed in the Big Craters complex along the trail. As the trail descends the west slope of Big Craters, it passes near small craters on the west flank of the complex.

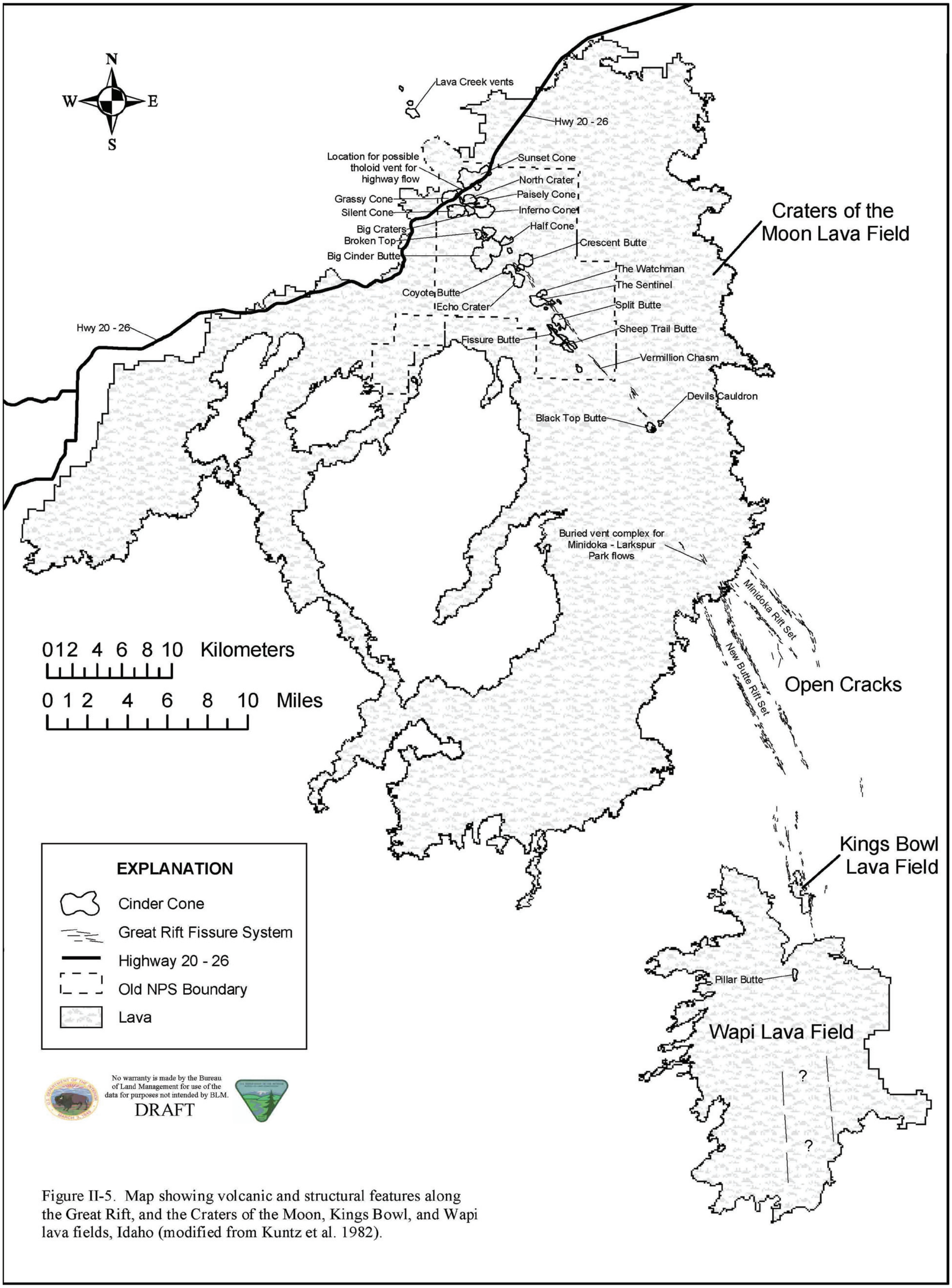


Figure II-5. Map showing volcanic and structural features along the Great Rift, and the Craters of the Moon, Kings Bowl, and Wapi lava fields, Idaho (modified from Kuntz et al. 1982).

Figure III-5. Map showing volcanic and structural features along the Great Rift volcanic rift zone, and the Craters of the Moon, Kings Bowl, and Wapi lava fields, Idaho (modified from Kuntz and others, 1992).

Where the trail flattens out, it passes near a few small fissures to the left of the trail. The trail crosses eruptive fissures, source vents for the Big Craters flows, in the area between the Big Craters complex and the southwest flank of North Crater. Big Craters flows traveled both east and northwest from this area. This lava has an olivine-green to greenish-brown crust, which is useful in distinguishing Big Craters flows in areas where they abut younger and older flows. The trail continues on and was described to this point under Stop III-2.

0.1 3.0 Vent for Inferno Cone. Vent area lies between the small spatter rampart and the low cinder mounds just south of the road and has been in filled by the Blue Dragon flow.

0.1 3.1 Big Cinder Butte on horizon. Blue Dragon slabby pahoehoe lies to the right between the road and the Spatter Cones. The west and south flanks of Inferno Cone are to the left.

0.5 3.6 Intersection to Tree Molds parking lot. Turn right.

0.3 3.9 Lava Cascades Turnout. Here, Blue Dragon lava flowed in a radial pattern from Big Sink, a perched lava pond. The pond is about 100-m long; when the pond drained back into the tube system, the still plastic pond crust draped down to form a depression about 15-m deep inside the levees that had formed at the edges of the pond.

0.3 4.2 Blue Dragon flow slosh-slab. On the left is a slab of Blue Dragon lava flow that mantles the lower north side of Broken Top. Either the flow was considerably inflated as it passed this site or the lava flow “sloshed” up onto the side of the cone as it changed direction to flow east. There are several other “slosh slabs” present in the Monument, some of which do not seem to be explained by either of these two mechanisms.

0.5 4.7 Crossing Blue Dragon slabby pahoehoe flow. Slabby pahoehoe is made up of jumbled plates or slabs of broken pahoehoe crust.

0.1 4.8 Park in Tree Molds parking lot for Stop III-3. Take a short break to visit restrooms. Hike about 2.5 km starting at Broken Top Loop trail. Following the stop, return to the parking lot and drive back to the loop road. Turn right on loop road.

Figure III-6. Aerial view of Broken Top cinder cone. Note slumping on top left side of cone; eruptive and noneruptive fissures (center of photo), and well-developed pressure plateau (lower part of photo).

## Stop III-3. Eruptive Fissures, Tension Cracks, and Eruption of Broken Top and Blue Dragon Flows at 2.1 Ka

The geology of the ESRP is characterized by Hawaiian-type basaltic volcanism, where eruptive fissures and dike emplacement features, such as tension cracks or noneruptive fissures, dominate the earliest stages. Flows of the COM lava field erupted from fissures and vents along the Great Rift, one of approximately nine described Pleistocene-Holocene, large-scale (>20 km) volcanic rift zones on the plain (fig. III-5; Kuntz and others, 1992). Faults, which are dike-emplacement features typically aligned with tension cracks in other examples of basaltic volcanism, rarely are seen within the volcanic rift zones on the ESRP. However, faults are found at the margins of the plain in the Arco-Big Southern Butte and Spencer-High Point volcanic rift zones (Kuntz and others, 1992, 2002; Hackett and Smith, 1992; Smith and others, 1996). Because of their locations, these faults are thought to be tectonic in nature rather than dike related, and therefore, part of the collinear extensions of the major, range-front faults for the Basin and Range mountains on the northern edge of the ESRP (Kuntz and others, 2002).

Figure III-7. Aerial view of Broken Top cinder cone. Note breakouts from pressure plateau of Broken Top pahoehoe flow (center right) that form lava toes on top of Blue Dragon flow (along left edge of photo).

The Great Rift consists of several major sets of tension cracks from north to south, respectively: COM lava field, Open Crack rift set, which consists of two rift-sets (New Butte and Minidoka), and the Kings Bowl lava field (fig. III-5). Within the COM lava field, there are numerous unnamed tension cracks and eruptive fissures related to cinder cone formation and lava flow eruptions. There are no known range-front faults located at the northern edge of the ESRP along the northwest trend of the Great Rift. However, there are mapped faults of appropriate trend located 1.2 km west of the Great Rift northwest of Grassy Cone. The drainage of Little Cottonwood Creek is on trend with the extension of the Great Rift that gives rise to the vent area for the Lava Creek flows. The Lava Creek flows, approximately 12 ka, are part of the COM lava field and represent the northernmost known extension of the Great Rift volcanic rift zone (Kuntz and others, 1992). We will discuss the tension cracks and eruptive fissures of the Great Rift associated with Broken Top, Big Cinder Butte, and Trench Mortar Flat at this stop.

We will be hiking about 2.5 km. Start by following the Broken Top loop trail, then cut cross-country over a pressure plateau and a cinder flat to look at eruptive and noneruptive fissures.

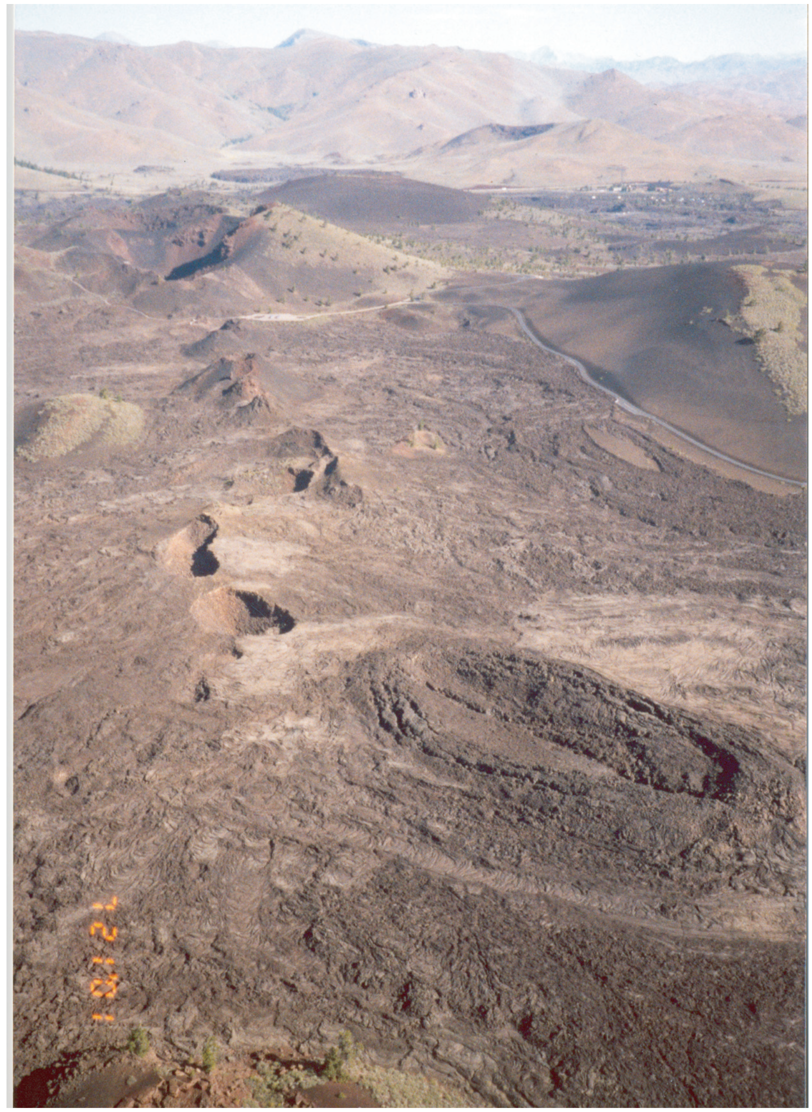

Figure III-8. Aerial view of the northern part of the Great Rift volcanic rift zone. From upper left to lower right: Pioneer Mountains, Big Craters cinder cone complex, Spatter Cones, pit craters, Little Sink (collapsed lava pond).

Follow the sidewalk east to where it "T's" into the main trail loop and turn right; do not take the trail to the left, which ascends Broken Top. The trail to the right parallels a fissure, which was the main source vent for Broken Top. This eruptive fissure has been partially in-filled by a tongue of the Blue Dragon flow. Follow the trail along the spatter rampart to the southeast then across the surface of the Blue Dragon flow. The southwest-facing wall of the eruptive fissure is heavily mantled with spatter and bombs that were erupted from the fissure. Many faults that trend parallel to the Great Rift cut the west side of Broken Top and slumping was active into the eruptive fissure (see fig. II-6). Walk along the trail to the contact of Broken Top flow with the Blue Dragon flow. Blue Dragon lava in this area is spiny pahoehoe, which forms from very thick, pasty lava. Spiny pahoehoe contains elongated gas bubbles on the surface that form spines, hence the name. The pahoehoe toes of the Broken Top flow that lie on top of the Blue Dragon flow broke out of the pressure plateau visible to the east (see fig. III-7). The Broken Top flow, though not dated, is stratigraphically younger than the Blue Dragon flow (~2.1 ka) and, therefore, the youngest flow in the COM lava field. Pressure plateaus may form from the sill-like injection of new lava beneath the crust of an earlier sheet flow that had not completely solidified.

After looking at classic lava-inflation structures, we will climb up onto the pressure plateau, follow the edge, and look at fissures visible from this vantage point. Hike may end while studying fissures most likely related to the 2.1-ka events associated with Trench Mortar Flat.

If time permits, we will make a quick stop at Buffalo Caves, in the Broken Top flow, and discuss lava-tube formation and hot and cold tube collapses. Buffalo Caves show many interesting features, such as lava stalactites, curbs (showing successive flow levels on the cave walls), ropes (showing flow direction), and stacked tubes.

If you follow the cairns east from Buffalo Caves to the intersection with the Wilderness Trail, you can turn left and make a loop up and over Broken Top. When you reach the Wilderness Trail, there also are good examples of shelly pahoehoe just to the east of the trail. Shelly pahoehoe forms from highly gas-charged lava, often near vents or tube skylights. Shelly pahoehoe contains small, open tubes, blisters, and thin crusts. Crusts here are about 10-cm thick, but in other parts of the Monument, they are as little as 2–3-cm thick. Also, just to the east of the trail, small chunks of agglutinated cinders can be found that were being transported away by the lava flow. Overlooks along the trail on the north and west sides of Broken Top provide insight into the plumbing system earlier described for the Blue Dragon flow (2.7 Inferno Cone Turnout). Figure III-8 is an aerial view showing the plumbing system that was described.

For teachers or others who are interested, there is 60-page teachers' guide to Broken Top Loop available on the Schools and Education section of the park web page.

| Mileage Inc. | Cum. | |
|---|---|---|
| 0.0 | 6.7 | Road to Caves Area on right; continue straight on loop road. |
| 0.2 | 6.9 | Devils Orchard blocky lava flow on right. |
| 0.3 | 7.2 | Intersection with the two-way portion of the loop road; turn right. |

| | | |
|---|---|---|
| 0.1 | 7.3 | Entrance into Devils Orchard spur road; continue on loop road. |
| 1.7 | 9.0 | Visitor Center |

## References


Fishel, M.L. 1993, The geology of uplifted rocks on Big Southern Butte—Implications for the stratigraphy and chemistry of the eastern Snake River Plain, Idaho: Pocatello, Idaho State University, unpublished M.S. thesis, 178 p.

Fremont, Brevet Captain John C., 1845, Report of the exploring expedition to the Rocky Mountains in the year 1842 and to Oregon and north California in the years 1843–1844: Washington, D.C., Blair and Rives, first edition, 583 p.

Hackett, W.R., and Smith, R.P., 1992, Quaternary volcanism, tectonics, and sedimentation in the Idaho National Engineering Laboratory area, *in* Wilson, J.R., ed., Field guide to geological excursions in Utah and adjacent areas of Nevada, Idaho, and Wyoming: Utah Geological Survey Miscellaneous Publications 92-3, p. 1–18.

Kuntz, M.A., Skipp, B., Champion, D.E., Gans, P.B., and Van Sistine, D., in press, Geologic map of the Craters of the Moon 30’ x 60’ quadrangle, Idaho: U.S. Geological Survey Miscellaneous Investigations Map, scale 1:100,000.

Kuntz, M.A., Anderson, S.R., Champion, D.E., Lanphere, M.A., and Grunwald, D.J., 2002, Tension cracks, eruptive fissures, dikes, and faults related to late Pleistocene-Holocene basaltic volcanism and implications for the distribution of hydraulic conductivity in the eastern Snake River Plain, Idaho, *in* Link, P.K., and Mink, L.L., eds., Geology, hydrology, and environmental remediation-Idaho National Engineering and Environmental Laboratory, eastern Snake River Plain, Idaho: Geological Society of America Special Paper 353, p. 111–133.

Kuntz, M.A., Skipp, B.A., Lanphere, M.A., Scott, W.E., Pierce, K.L., Dalrymple, G,B., Champion, D.E., Embree, G.F., Page, W.R., Morgan, L.A., Smith, R.P., Hackett, W.R., Rodgers, D.W., 1994, Geologic map of the Idaho National Engineering Laboratory and adjoining areas, eastern Idaho: U. S. Geological Survey Miscellaneous Investigations Series Map I-2340, scale 1:100,000.

Kuntz, M.A., Covington, H.R., and Schorr, L.J., 1992, An overview of basaltic volcanism of the eastern Snake River Plain, Idaho, *in* Link, P.K., Kuntz, M.A., and Platt, L.B., eds., Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 227–267.

Kuntz, M.A., Champion, D.E., Spiker, E.C., Lefebvre, R.E., 1986, Contrasting magma types and steady-state, volume-predictable, basaltic volcanism along the Great Rift, Idaho: Geological Society of America Bulletin, v. 97, p. 579–594.

The North Crater Neighborhood—More complex than Mr.Rogers’, *http://data2.itc.nps.gov/nature/documents/field%5Ftrip%5Ftext%5F2%2D1%2Epdf*.

Smith, R.P., Hackett, W.R., and Rodgers, D.W., 1989, Geologic aspects of seismic-hazard assessment at the Idaho National Engineering Laboratory, southeastern Idaho, *in* Proceedings, Second Department of Energy Natural Phenomena Hazards Mitigation Conference: Livermore, California, Lawrence Livermore National Laboratory, p. 282–289.

Smith, R.P., Jackson, S.M., and Hackett, W.R., 1996, Paleoseismology and seismic hazard evaluations in extensional volcanic terrains: Journal of Geophysical Research, v. 101, p. 6277–6292.

Spear, D.B., and King, J. S., 1982, The geology of Big Southern Butte, Idaho, *in* Bonnichsen, B., and Breckenridge, R.M., eds., Cenozoic geology of Idaho: Idaho Bureau of Mines and Geology Bulletin 26, p. 395–404.

Stuiver, M., and Polach, H.A., 1997, Reporting of $^{14}C$ data: Radiocarbon, v. 19, p. 355–363.

Valastro, S., Jr., Davis, E.M., and Zarela, A.G., 1972, University of Texas radiocarbon ages: Radiocarbon, v. 14, p. 468–470.