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A Review of Scientific Research at Craters of the Moon National Monument

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Cover: Sheeptrail Butte, a composite cinder cone at Craters of the Moon National Monument. Photo courtesy of the National Park Service.

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We are grateful to the personnel at Craters of the Moon National Monument for their cooperation and support throughout this project and to the staff at the University of Idaho Library for assistance with computerized literature searches.

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INTRODUCTION

Because of their biological, physical, and cultural resources, large expanses of undisturbed environments, and management policy of resource protection, national parks are attractive areas for research. Research has served several functions in parks. These include providing information for interpretive talks and displays, providing the data necessary to monitor and protect the park's natural resources, and helping to develop management practices to restore altered ecosystems and maintain those that are healthy. There has, however, been little documentation of the history of research conducted in a typical park.

This report documents the research history of Craters of the Moon National Monument. Its intent is to provide a comprehensive overview of what is known about the monument's natural and cultural history. It will provide a background for future research and planning as well as an assessment of the current status of our knowledge about the monument's ecosystems.

This report forms an important first step in a series of research studies the National Park Service plans to undertake during the next few years. In addition, this report's tabular summaries of research (Appendix 1) will be used to start a computerized data management system for the monument.

This report primarily reviews those studies conducted within or including the monument's boundaries. But because relatively little wildlife research has been done at the monument, the review of the wildlife literature was extended to include studies at the Idaho National Engineering Laboratory (INEL). The 2,315-square-kilometer INEL lies approximately 24 kilometers east of Craters of the Moon National Monument and has similar physiography and vegetation. INEL was designated a National Environmental Research Park in 1975. Since then, extensive studies applicable to Craters of the Moon have been carried out on many of INEL's animal species.

OVERVIEW

Craters of the Moon National Monument occupies 217 square kilometers at the northern edge of the Snake River Plain and lies 29 kilometers southwest of Arco, Idaho. Most of the monument contains geologically recent cinder cones, lava flows, and other volcanic features of the Great Rift. The monument's north end, north of Highway 93, includes foothills of the Pioneer Mountains. Elevations in the monument range from 1,625 to 2,355 meters. The tallest cinder cone, Big Cinder Butte, rises more than 200 meters above the surrounding plain.

Vegetation

Fifty-eight percent of the monument consists of relatively barren lava flows (less than 15 percent plant cover). Sagebrush - (*Artemisia* spp.) dominated community types cover more than 30 percent of the area. Limber pine (*Pinus flexilis*) grows on cinder cones and in cinder gardens (7 percent of the monument), and Douglas-fir (*Pseudotsuga menziesii*) occurs on the north-facing slopes of older cinder cones (0.1 percent of the monument). Riparian areas occupy 0.13 percent of the monument (Day and Wright 1985).

Climate

A National Oceanic and Atmospheric Administration weather observation station records daily maximum and minimum temperatures and measurable precipitation at Craters of the Moon National Monument. Wind speed is measured with a cup anemometer.

In addition, a convertible data-collection platform measures temperature, precipitation, humidity, and barometric pressure. Data are transmitted to the Geostationary Operational Environmental Satellite and used by the Bureau of Reclamation for flood prediction and control.

Annual precipitation during 1959-1982 averaged 42.6 centimeters and had a bimodal distribution, with the major peak, resulting from snow, in December-January and a second peak, resulting from rain, in May (Day 1985). Average monthly maximum temperatures during this period ranged from -1.7ºC in January to 28.7ºC in July (Griffith 1983).

Mining

Silver mining in south-central Idaho peaked between 1880 and 1902. The Lava Creek Mining District, which includes the north end of Craters of the Moon National

Monument, also experienced a high level of mining around 1913 (Craters of the Moon National Monument 1987). The Martin Mine was located on what is now monument property. Rights to the Martin Mine were transferred to the monument in 1963, and most of the structures associated with the mine have been removed. Today, mining continues on a small scale outside the monument, in the Lava Creek District.

Grazing

Livestock grazed at Craters of the Moon prior to its establishment as a national monument. In the 1870s, large bands of sheep ranged throughout the area. An early resident, Mr. Martin, constructed a cement livestock watering trough at Yellowjacket Waterhole.

After lands fell under the jurisdiction of the National Park Service (NPS), sheep grazing was limited to 60 hectares in the monument's north end that could not practically be fenced. Some additional grazing undoubtedly occurs by trespassing livestock. Grazing also continues on adjacent Bureau of Land Management (BLM) lands.

Logging

Wunner (1967) reported that Douglas-fir was logged from the north side of Silent Cone prior to the monument's establishment. Later, in the early 1960s, over 6,000 limber pines were poisoned or felled in an attempt to eradicate dwarf mistletoe (discussed later in this report). No other published accounts of timber harvest could be found.

Fire

Evidence of periodic fires exists at Craters of the Moon National Monument, but few fires have been documented. Fire ecology is currently being studied to determine the monument's fire history and to produce a fire management plan.

In cooperation with the BLM, an AFIRMS Fire Weather Station has operated during the fire season since 1980. The station monitors minimum and maximum temperatures, wind speed and direction, cloud cover, humidity, fuel moisture, and lightning activity.

Air Quality

The 175-square-kilometer congressionally designated wilderness area at Craters of the Moon National Monument is designated Class I for air quality management. A monitoring program at the monument provides data on suspended particulate material, particulate fallout, acid rain, and visibility.

A high-volume particulate air sampler at the monument has operated since 1974 in cooperation with the Idaho Department of Health and Welfare's Division of the Environment. This device draws air through a glass-fiber filter and is capable of extracting 99.9 percent of particles whose diameters are equal to or greater than 0.3 microns. In 1984, the division officially stated that the data from this sampler represented the cleanest air in the continental United States and that the Environmental Protection Agency (EPA) was using it as baseline reference for visibility.

A low-volume continuous air sampler operated by the Department of Energy's Radiological and Environmental Science Laboratory at the Idaho National Engineering Laboratory (INEL) monitors radioactivity carried from the INEL Site. The sampler's filters collect 99 percent of both airborne particulate radioactivity and elemental iodine vapor. Sampling results indicate normal levels of naturally occurring radiation at the monument.

In cooperation with the BLM, NPS collects data for the National Atmospheric Deposition Program. An atmospheric deposition sampler, operating since 1980, collects wet and dry fallout. Samples are analyzed for pH, specific conductance, and chemical components. Preliminary results show that atmospheric deposition at the monument is relatively acid-free.

In 1982, as part of a program to monitor visibility in Class I areas, the NPS installed a telephotometer at Craters of the Moon National Monument. The telephotometer measures light reflected from the sky and from its target, Big Southern Butte, southeast of the monument. Simultaneous with the telephotometer readings, photographs are taken with a 35-mm camera, which later are used to correlate light measurements with visibility. Since 1986, an automated camera system has been used. Data are sent to Air Resource Specialists, Inc., Fort Collins, Colorado, for compilation and computer storage.

In 1984, Craters of the Moon National Monument cooperated with EPA Region X and the states of Washington, Oregon, and Idaho in the Pacific Northwest Regional Haze Study. The objectives of the study were to: define the geographical extent of haze, determine the frequency of occurrence of regional haze episodes, measure concentrations of fine particles (less than 2.5 microns), chemically characterize the aerosols, identify sources of fine-particle emissions, conduct transport and trajectory analyses, and develop source-receptor relationships. This information will be used to develop visibility Class I state implementation plans for each participating state. Results of this project were not yet available when this manuscript was being prepared.

A NPS scientist from the Air Quality Division noted possible air pollution injury to plants at Craters of the Moon National Monument (Bennett 1985). Red-banded tipburn, possibly caused by hydrogen fluoride, was observed on limber pines. Possible sources of the pollutant include phosphate-fertilizer plants in Pocatello, Idaho, about 100 kilometers from the monument. Dark stippling on chokecherry (*Prunus virginiana*) and black necrosis on aspen (*Populus tremuloides*) were observed on a few plants. These are symptoms of ozone injury.

Bennett (1985) identified eight plant species and one mammal species that could serve as biological indicators of the monument's air quality. The organisms are sensitive to one or more of the following pollutants: ozone, sulfur dioxide, hydrogen fluoride, and heavy metals. Bennett recommended baseline inventories using plants and animals to monitor pollutants. In addition, Bennett recommended that an ozone monitoring station be installed and that a flora and a map of lichens and mosses be compiled.

Seismic Monitoring

A temporary seismographic monitoring station was operated May through September 1986 in cooperation with INEL (results are not yet available). A permanent seismographic station may be installed in the future.

HISTORY

The first documented exploration of the periphery of the Craters of the Moon area was led by Benjamin L. E. Bonneville, a trapper who extended the search for fur beyond the Snake River in 1833-1834 (Ostrogorsky 1983). Stearns (1931) believed that the area also was visited sometime during 1840-45 by Father DeSmet, a Belgian priest.

During the 1840s and 1850s, thousands of emigrants crossed the Snake River Plain on the Oregon Trail. By 1862, hostilities between emigrants and Native Americans along the Snake River had intensified to the extent that emigrants left the Snake River at Fort Hall and instead took Goodale's Cutoff, which ran along the northern edge of the Snake River Plain and skirted the Craters of the Moon lava field. A portion of Goodale's Cutoff passes through the north end of Craters of the Moon National Monument. Diaries of the emigrants vividly describe the Craters of the Moon area (Ostrogorsky 1983). By 1904, pioneers referred to the area as Craters of the Moon.

Stearns (1928a) reported that Arco resident J. W. Powell searched for livestock water supplies in the Craters of the Moon lava field in 1879 and again, with Walter Ferris, in the 1880s. In 1901, I. C. Russell of the U.S. Geological Survey (USGS) led the first scientific exploration of the northern Craters of the Moon area. In 1921, Harold T. Stearns, also of the USGS, explored the area in greater detail and recommended the creation of Craters of the Moon National Monument (Stearns 1983). Robert L. Limbert (1924), a taxidermist and adventurer from Boise, Idaho, also explored the Craters of the Moon area in the early 1920s and named many of the monument's geologic features.

On May 2, 1924, President Calvin Coolidge proclaimed 101 square kilometers as Craters of the Moon National Monument. After Stearns returned to the monument in 1926 to finish surveying the area, the monument was expanded to 215 square kilometers (Ostrogorsky 1983).

In 1962, 21.65 square kilometers were added to protect the 0.73-square-kilometer Carey Kipuka for scientific study. In 1970, 175 square kilometers were set aside as the Craters of the Moon Wilderness Area.

GEOLOGY

The geology and volcanic history of Craters of the Moon National Monument has been the subject of intense scientific study for more than 80 years, often by some of the United States' most famous geologists. These studies have produced a wealth of data as well as conflicting estimates of the age of the monument's lava flows and of the history of its eruptions. The major geological studies are summarized in this section.

Relationship of Craters of the Moon National Monument to Surrounding Areas

Greeley (1977) proposed the term "plains" volcanism to describe the type of volcanism of the central Snake River Plain, of which Craters of the Moon National Monument is a part. Plains volcanism is characterized by low shield volcanoes, tube-fed lava flows, fissure-fed flows, and intracanyon flows. In thickness and extent of flows, it is intermediate between flood lava flows and shield volcanoes. Plains volcanism produced individual lava flows about 10 meters thick from central vents and short fissures.

The Craters of the Moon lava field covers 1,600 square kilometers, contains more than 30 cubic kilometers of lava flows and pyroclastic deposits, and is the largest predominantly Holocene lava field in the coterminous United States (Kuntz et al. 1986a). The field includes at least 60 lava flows, 25 cinder cones, and eight eruptive fissures. Most of its cones and fissures lie within Craters of the Moon National Monument (Fig. 1).

Similarities between Craters of the Moon and other volcanic areas of the world (e.g. Hawaii, Iceland, and Italy) have been noted by Stearns (1931) and others. Parsons (1975) observed that "Big Craters and the associated spatter cones at Craters of the Moon National Monument are nearly identical in size and shape to the 1960 Kopoho Craters and associated spatter cones on the Puna Rift Zone of Kilauea," Hawaii. The lava tunnel system at Craters of the Moon National Monument also is similar to tunnels near Alae Crater at Kilauea.

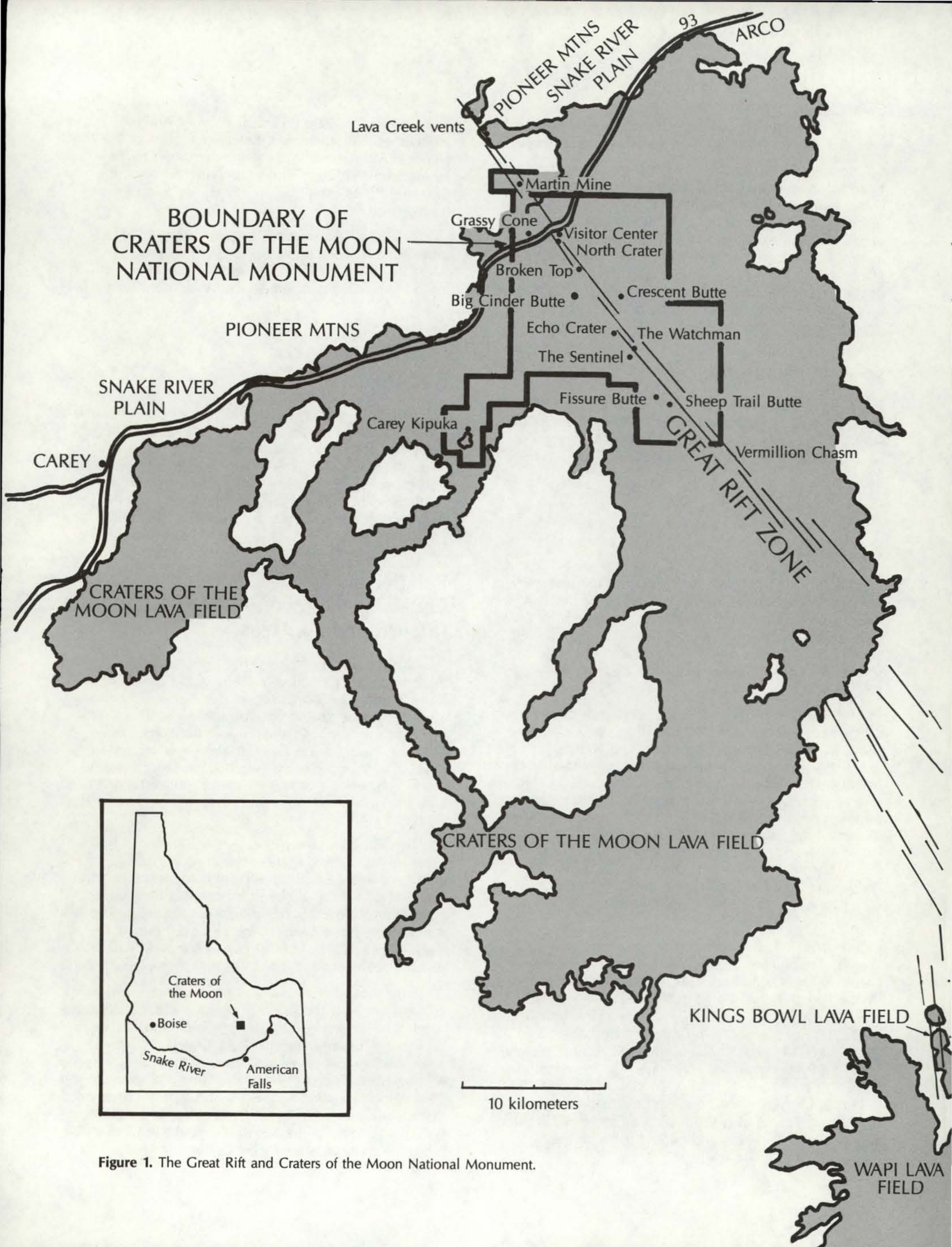

Figure 1. The Great Rift and Craters of the Moon National Monument.

The Great Rift

Prinz (1970) proposed the term "Idaho Rift System" for the 100-kilometer-long, north- to northwest-trending series of fissures across the Snake River Plain. The Idaho Rift System is composed of four separate rift sets, which are, from north to south: the 55-kilometer-long Great Rift set, the 21-kilometer-long Open Crack rift set, the 11-kilometer-long Open Crack rift set, the 11-kilometer-long Kings Bowl rift set, and the 18-kilometer-long Wapi rift set. The Open Crack rift set emerges from the southern edge of the Craters of the Moon lava field. Kuntz et al. (1986a) consider the Great Rift to be the 85-kilometer-long volcanic rift zone along which lie the Craters of the Moon, Kings Bowl, and Wapi lava fields.

The Great Rift was first noticed in 1921 by O.E. Meinzer of the U.S. Geological Survey (Stearns 1924). Twenty-one kilometers of the Great Rift lie within Craters of the Moon National Monument (Prinz 1970). Manifestations of the Great Rift within the monument are aligned cinder cones, craters, spatter cones, and spatter ramparts, and basaltic lava flows leading in opposite directions from depressed areas (Shepherd 1936a, 1936b; Prinz 1970).

Anderson (1929a, 1929b) described two small cinder cones, North Vent and South Vent, that are extensions of the Great Rift 7-10 kilometers from the Snake River Plain in the foothills of the Pioneer Mountains. Lava from South Vent flowed more than 10 kilometers, descending Lava Creek for more than 580 meters and pouring onto the Snake River Plain. A small spatter cone between North and South vents and an open vertical fissure or fracture in line with South Vent also are in this area. In addition, the Dry Fork of Antelope Creek, containing lava from North Vent, is unusually straight and in line with the Great Rift. Because there is no evidence of a rift or fissure in the 7 kilometers between the northern-most vent of the monument and South Vent, the fact that North and South vents are related to the Great Rift was unknown until both they and the Craters of the Moon National Monument were accurately mapped.

Faler et al. (1971) measured sub-surface temperatures in the Great Rift area using sucrose solutions buried underground for approximately 303 days. This method is based on the relationship between temperature and the rate of acid-catalyzed sucrose hydrolysis. Thirty samples were buried along 4 kilometers of the Great Rift within Craters of the Moon National Monument, and 150 samples were buried along a 40-kilometer stretch running south-southwest away from the Great Rift.

Faler et al. (1971) assumed that sub-surface temperatures would decrease with distance from the Great Rift, which, as suggested by the location of the most recent eruptions on the Snake River Plain, is believed to be centered over a large heat source. Results of this experiment, however, indicated that sub-surface temperatures increase with distance from the Great Rift. Faler et al. suggested this may be due to faults along the southern edge of the eastern Snake River Plain that increase local heat through heat transfer into percolating ground water or through simple conduction. Alternatively, heat beneath the Great Rift may be blocked from reaching the earth's surface by the unfaulted, thick, recent lava flows and sediments of the Craters of the Moon lava field.

Volcanic History of Craters of the Moon Lava Field

Age of the Lava Flows

Early Estimates. The earliest published estimate of the age of Craters of the Moon lava flows is Russell's (1902). Because of the lava's fresh appearance and the limber pines' size, Russell judged the most recent flows to be not more than 100 or 150 years old. Stearns (1924) also was impressed by the apparent youth of the lava flows, but noted that one would expect the amount of vegetation on flows in the arid climate of the Snake River Plain to be less than in volcanic areas of similar age in the humid climate of Hawaii. Stearns (1928a, 1928b) counted 461 rings in a core from a tree growing on a pahoehoe flow near Big Craters, and estimated that the most recent eruptions occurred 250-1,000 years previously. After a core taken in 1954 from the Triple Twist Tree showed that it was at least 1,350 years old, Stearns (1963) revised his estimate of the age of the most recent lava to at least 1,650 years.

Radiocarbon Dating. Prinz (1970) reported that based on radiocarbon dating, a sample of charred sagebrush taken from below the lowest flow of the Kings Bowl rift was 2,130 $\pm$130 years old. This was believed to represent the time the Kings Bowl Rift opened and was presumed to be the approximate age of the entire Idaho Rift System.

In 1969, two samples of charred shrub (probably sagebrush) rootlets were retrieved from the lower surface of a pahoehoe flow by tunneling beneath the eastern edge of the Craters of the Moon lava field, east of Blacktail Cinder Cone. Radiocarbon dates for the samples were 2,110 $\pm$90 and 2,050 $\pm$80 years before present (BP). Attempts in 1970 to obtain samples from beneath four other flows were unsuccessful, due in three cases to "fill" at the edges of the flows and, in the fourth case, because insufficient amounts of charcoal were found (Bullard and Rylander 1970; Bullard 1971a, 1971b, 1976).

In 1970, charcoal samples were obtained from beneath five tree molds at Trench Mortar Flat and were determined to have radiocarbon ages of from 2,130 $\pm$80 years BP to 2,310 $\pm$80 years BP. Charcoal taken from one tree mold near the northwest base of The Watchman had a radiocarbon age of 2,140 $\pm$60 years BP (Bullard 1971a, 1971b, 1976; Valastro et al. 1972). (At the base of the trunk of one large tree mold Bullard (1971a) found the charred axis of a pine cone, which Carl Urban identified as that of a limber pine (*Pinus flexilis*).)

Kuntz et al. (1986b) excavated with backhoes below the margins of about 20 lava flows and dug by hand at tree molds in three flows to obtain carbon-bearing sediment and charcoal fragments. Radiocarbon ages of 35 samples ranged from about 15,000 to 2,000 years BP.

Paleomagnetic Measurements. Each lava flow in the Craters of the Moon lava field reflects the local geomagnetic field when the lava erupted and cooled (Kuntz et al. 1982). Champion and Shoemaker (1977) showed that the direction of magnetization of a lava flow in the Craters of the Moon lava field could be determined within 2 degrees with 95 percent confidence. Differences in direction of magnetization that correspond to differences in age of from 20 to 50 years generally can be resolved. These differences allow flows of similar paleomagnetic direction to be placed into groups of similar age.

In 1926, Stearns (1931) was the first to attempt to use the paleomagnetic method to age lava flows in Craters of the Moon National Monument. Because the declinations of 14 flows were not much different from the magnetic declination in 1926, Stearns suggested that the flows were extruded within the previous 1,000 years.

More recent paleomagnetic measurements indicate that there have been at least six short eruptive episodes at the Craters of the Moon lava field, beginning about 11,000 years BP (Champion and Shoemaker 1977). Kuntz et al. (1986a) obtained paleomagnetic measurements of 1,282 cores taken from 100 sites on 41 flows of the Craters of the Moon lava field.

Eruptive Periods

Stearns (1928b, 1931) believed that there were three eruptive epochs along the Great Rift. Based on stratigraphic relationships and amount of vegetational cover, he listed an approximate eruptive sequence of 27 lava flows at Craters of the Moon National Monument. Later, Murtaugh (1961) recognized four eruptive periods with a significant time interval apparent only between the oldest and second oldest.

Kuntz (1985) and Kuntz et al. (1982, 1983, 1986a, 1986b) conducted extensive studies of the evolution of the Craters of the Moon lava field over a 15-year period. These field and laboratory studies produced large amounts of radiocarbon, paleomagnetic, petrographic, and chemical data that disputed the findings of Stearns and Murtaugh. These studies indicated that lava flows of the Craters of the Moon lava field were emplaced during at least eight eruptive periods that began about 15,000 years ago and ended about 2,000 years ago. Each period lasted not more than several hundred years (Table 1).

Table 1. Eruptive periods, radiocarbon ages, and informal names of lava flows in the Craters of the Moon lava field. After Kuntz et al. 1986a.

Eruptive Period	Radiocarbon age[1]	Informal name and lava type of major flows[2]
A	n.d.	Broken Top (p)
	2,076 ± 45	Blue Dragon (p)
	2,205 ± 25	Trench Mortar Flat (p)
	n.d.	North Crater (p)
	2,400 ± 300	Big Craters (Green Dragon) (p)
	n.d.	Serrate (a-b)
	n.d.	Devil's Orchard (a-b)
	n.d.	Highway (a-b)
B	n.d.	Vermillion Chasm (p)
	4,300 ± 60	Deadhorse (p)
	3,660 ± 60	Devil's Caulldron (p)
	3,590 ± 70	Minidoka (p)
	n.d.	Larkspur Park (p)
	4,510 ± 100	Rangefire (p)
	n.d.	Blacktop (p)
C	n.d.	Indian Wells North (a)
	n.d.	Indian Wells South (a)
	6,020 ± 60	Sawtooth (a)
	n.d.	South Echo (p)
	n.d.	Sheep Trail Butte (p-a)
	n.d.	Fissure Butte (p-a)
	n.d.	Sentinel (p)
D	n.d.	Silent Cone (a)
	6,600 ± 60	Carey Kipuka (a)
	6,500 ± 60	Little Park (a)
	n.d.	Little Laidlaw Park (a)
E	7,360 ± 60	Grassy Cone (p)
	7,470 ± 80	Laidlaw Lake (p)
	7,840 ± 140	Lava Point (a)
F	10,240 ± 120	Pronghorn (p)
	10,670 ± 150	Heifer Reservoir (p)
	11,000 ± 100	Bottleneck Lake (p)
G	12,010 ± 50	Sunset (p)
	12,000	Carey (p)
	12,760 ± 150	Lava Creek (p-a)
H	15,100 ± 160	Kimama (p)
	n.d.	Bear Den Lake (p)
	n.d.	Baseline (p)
	n.d.	Little Prairie (p)
	n.d.	Lost Kipuka (p)
	n.d.	No Name (p)
	n.d.	Brown Flow (p)

[1] n.d. = not determined.

[2] p = chiefly pahoehoe flows; a-b = aa and block flows; a = chiefly aa flows; p-a = pahoehoe and aa flows.

The intervals between eruptive periods at the Craters of the Moon lava field ranged from several hundred to about 3,000 years and averaged about 2,000 years. Kuntz et al. (1986b:174) noted that "because the present interval has lasted 2200 years, another eruptive period seems likely to occur within the next 1000 years."

Magma Output

Magma output at the Craters of the Moon lava field was constant at about 1.5 km^3/1,000 years from 15,000 years BP to 7,000 years BP and about 2.8 km^3/1,000 years from 7,000 to 2,000 years BP (Kuntz et al. 1986a). "Eruptions began when enough magma accumulated in a reservoir to create a critical pressure of about 100 bars that exceeded lithostatic pressure and tensile strength of wall rocks" (Kuntz 1985). "Field and geophysical data and mathematical models suggest a mantle source 50-70 km deep, a reservoir volume about 10 km^3, and feeder dikes about 1-3 km long and as wide as 2 m. Magma probably rose at rates of about 1 m/sec and large volume flows (about 3 km^3) were emplaced within a few days to a few weeks" (Kuntz 1985).

The volume of an eruption is proportional to the duration of the previous quiescent period and to the long-term output rates (Kuntz et al. 1986a). Further, the steady-state nature of this volcanism and the constancy of the most recent output rate suggested to Kuntz and his co-workers that 5-6 cubic kilometers of lava will be erupted in the next eruptive period. Because past eruptions at the Craters of the Moon lava field have generally occurred in areas of the Great Rift that have been quiescent the longest, they predicted the next eruption will begin in the central part of Craters of the Moon National Monument, from Big Cinder Butte to Sheep Trail Butte, and, possibly, will move to the northern part of the Great Rift, from Lava Creek vents to Big Cinder Butte (Kuntz et al. 1986a).

General Geological Reconnaissance and Descriptions

Volcanoes

Russell (1902) noted that the volcanoes in southern Idaho may be divided into two classes that grade into each other: (1) lava mounds and (2) cinder and lapilli cones. Russell considered that in most, if not all instances, cinder and lapilli cones preceded lava mounds. Liquid lava, issued during the later stages of eruptions, destroyed or buried the cones, creating lava mounds.

Russell (1902) found many examples illustrating that eruptions were often violent at first, characterized by explosions and the growth of cinder cones. Later, lava rose within the cones and flowed out in streams that sometimes carried away parts of crater walls. Some of the crater-wall masses, up to 18 meters in diameter and 6 meters high, were believed to have floated as far as 4.5-6.5 kilometers on top of lava flows. These masses have moat-like depressions around their bases, evidence that they floated on top of lava flows rather than being surrounded by molten lava (Russell 1903).

Russell (1902) also noted that the spatter cones 3.2 kilometers northwest of Big Cinder Butte are an exception to the rule that the area's eruptions ended with lava flows. Rather, these spatter cones formed along a fissure in the hardened surface of a lava stream when the lava below was still plastic or liquid.

Stearns (1928b) recognized three types of cones: cinder cones, spatter cones, and lava domes. Lava domes were believed to have formed by the quiet and continuous welling out of pahoehoe lava. Examples of lava domes are at Owl Cavern, Indian Tunnel, and Surprise Cave.

Many of the monument's cinder cones are elongated to the northeast, presumably the result of prevailing southwest winds at the time of their formation. Stearns considered Big Cinder Butte to be one of the largest purely basaltic cinder cones in the world (Stearns 1928a).

Lava Flows

There are two general types of lava flows at Craters of the Moon National Monument: aa and pahoehoe. Extensive study has been devoted to describing and characterizing the individual flows. The first study of lava flows was by Russell (1902), who identified six principal lava flows that originated from the "Cinder Buttes" and estimated that they cover 647-777 square kilometers. Average thickness of the flows was estimated to be 23 meters. He observed that pahoehoe flows occur most frequently near the sources of lava streams. According to Stearns (1931), pressure domes in pahoehoe flows were caused by buckling of the crust while lava still flowed below. Later, the crust subsided.

The surface of aa flows was described as angular blocks of scoriaceous lava (Stearns 1931). Some of the lava blocks have wrinkled and corrugated surfaces, which were believed to show that the aa flows "existed as pahoehoe before they were broken and displaced" (Russell 1902:98). Short, sharp spines on the surface of aa blocks were apparently caused by escaping gas which pulled out stringers of lava (Stearns 1931).

Whether a flow produced an aa or a pahoehoe surface was attributed to the ratio between the lava's rate of cooling and its rate of motion (Russell 1902). Stearns (1931), however, believed that the heat and gas contents of the lava determined whether a flow was pahoehoe or aa.

Murtaugh (1961) proposed the term "squeeze outs" to describe tongues of pahoehoe issued from the margins of aa and block-lava flows. Russell (1902) named the Blue Dragon Lava Flow for its deep-blue surface and serpent-like surface ridges and cracks.

Nichols and Stearns (1940) examined lava from Big Craters and determined that the lava's grooves and striations were caused by pyroclastic material (blocks, bombs, and lapilli) falling onto molten flows, indicating that during some periods, lava and pyroclastics were simultaneously extruded from the cones. Fragments are frequently found imbedded at the downhill ends of the grooves.

Kuntz et al. (1986b) calculated area and volume of lava flows using a planimeter, geologic maps, and field measurements of flow thickness. Average flow thicknesses were: Shelly pahoehoe from fissure eruptions, 5 meters; tube- and surface-fed pahoehoe flows, 10 meters; aa flows, 15 meters; blocky aa flows, 20 meters.

Volcanic Rock Fragments

Russell (1902) classified volcanic rock fragments from the "Cinder Buttes" as dust, lapilli, scoriae, clots, lava cakes, and bombs. Variations in the form of volcanic ejecta, from highly fluid lava to brittle scoria, were attributed to the degree of fluidity or rigidity of lava leaving the parent crater. Further, plastic or fluid lava assumed various shapes that depended on the length of its aerial flight and its manner of rotation.

Lapilli are angular fragments of highly scoriaceous lava ranging from about 0.6 to 2.5 centimeters in diameter. Consolidated lapilli forms "tuff." Dust and lapilli is "material which presumably hardened on the surface of liquid lava within a crater and was broken and blown out by steam or other explosions and fell about the opening from which it came or was widely distributed by the wind . . . " (Russell 1902:74).

Highly viscous lava clots were blown out by mild explosions and fell nearby, building scoria cones (Russell 1902). Scoria is composed of rough, ball-like masses of lava, usually 20-40 centimeters in diameter, expelled from craters in a highly plastic or semi-fluid condition. Soft enough to adhere to each other after coming to rest, these lava masses became highly scoriaceous and roughly spherical during their flight.

Lava cakes are composed of compact lava, 0.6-1.7 centimeters thick and up to 35.6 centimeters across. They occur on the sides of some cones and crater walls (Russell 1902). According to Russell (1903), compact beds of lava amid the scoria or lapilli of cinder cones formed from liquid or highly plastic splashes and clots of lava running together.

Lava bombs formed as masses of highly viscous or fluid lava were thrown high in the air. Bombs became more or less spherical due to rotation during their flight. One type of bomb has a dense crust and highly vesicular interior, with larger vesicles in the center and smaller vesicles toward the surface. Russell (1902) hypothesized that this arrangement was caused by cooling from the outside, which forced gases inward. As the gases inside expanded, the surfaces cracked in a process similar to the formation of bread crust, hence the name "breadcrust bombs." Breadcrust bombs show no signs of rotation and occur on inner crater walls, indicating a short aerial flight (Russell 1903).

A second type of bomb, the spindle bomb, is compact, with no outer rind. Interior steam cavities often are arranged in concentric bands accompanied by concentric lines or cracks. Russell (1902) believed that these bombs may have formed from masses of viscous lava, similar to lava cakes, which rolled together during their rotational flight and assumed football-like shapes, with projections at both ends of the long axis.

A third type of bomb, pear- or tear-shaped bombs, ranges up to 0.6 meters in diameter. Many of these bombs were apparently still plastic upon striking the ground, as evidenced by lapilli partially imbedded in their outer crusts (Russell 1903).

Ribbon bombs are a fourth type of bomb. Some are the broken ends of spindle bombs. Others formed in the air as two clots of molten lava pulled away from each other (Stearns 1928a, 1928b). Examples of these volcanic fragments are found in the monument's museum collections. Unfortunately, because collectors removed many specimens before the monument's establishment and vandals have removed them since, natural examples are rare.

Tree Molds

There are two types of tree mold at Craters of the Moon National Monument. Molds of one type exist as holes in lava flows. Molds of the second type, known as "lava trees," rise above the lava's surface. Lava trees formed when lava flowed over trees and then receded, or when spatter from a spatter vent covered trees (Stearns 1928a). The average diameter of 81 tree molds at Trench Mortar Flat was 36.6 centimeters; the largest diameter was 1 meter (Bullard 1971a).

Water and Ice

Water and ice occurs in three situations at Craters of the Moon National Monument: (1) depressions where snow collects in winter, (2) lava caves or tubes where water that percolates inside freezes in drafts of cold air, and (3) deep inverted-funnel craters of spatter cones (Stearns 1924, 1928a). Persistent water always is perched on bodies of ice (Stearns 1928b, Stearns et al. 1938). Wells drilled near the monument indicated that ground water was at least 306 meters below the surface (Stearns et al. 1938).

Caves, Arches, and Cones

Individual lava caves, arches, and spatter cones were mapped and described by Sanchez and Peck (1959), Sanchez (1960), and Peck (1953, 1974a). A comprehensive survey of all known lava caves (53), cones, and natural bridges in the monument was completed in 1984 (Jex 1984). Caves were classified according to the hazards they presented, the skills required to explore them, and their archaeological, biological, and geological contents. Also noted for each cave were the type and number of entrances, lengths of passages, cave pattern and directional trend, vertical relief, presence of water, present management, and, based on the cave's fragility and the danger it might pose to visitors, the type of protection needed from the National Park Service.

Stalactites

Lava stalactites in lava tubes appear to have formed by several mechanisms. Viscous lava, dripping from ceilings, created stalactites whose cross sections are rounded. Some have bulbous tips, indicating that hot gases remelted solidified lava. Other stalactites appear to have been stretched from the ceiling by a flow of lava below. These stalactites are not rounded in cross section and often are not perpendicular to the ceiling (Sanchez 1960, Murtaugh 1961). Similarly, pillars between layers of lava-tube roofs appear to have formed when a lower layer of plastic lava sagged away from the former lava-tube ceiling (Murtaugh 1961).

Mapping the Craters of the Moon Lava Field

Ground Mapping

Murtaugh (1961) prepared a detailed geologic map of Craters of the Moon National Monument that recognized more than 50 separate lava flows. Individual flows, major and minor features of the flows, vent structures, and volcanic ejecta were described.

Sidle (1979) mapped the geology of the north end of the monument and its surrounding areas. According to Sidle, Mississippian Drummond Mine limestone (30 meters thick) and Scorpion Mountain formations (488 meters thick) are the oldest rocks in that area. Its limestone, conglomerates, and quartzite were deposited during the Mississippian Period. Thrusting from the west during the late Mesozoic Era caused northwest-trending folds and faults. Volcanism began during the Eocene Epoch, filling the valleys with at least 1,181 meters of Challis rhyodactite block lava flows and pyroclastic rocks. The Challis volcanic rocks are intruded by biotite granite, hornblende quartz monzonite, and small plutons and dikes ranging from 35 million to 85 million years old. Sulfide mineralization occurred near the intrusions. Holocene alluvium has partially filled Big and Little Cottonwood Creek drainages.

Remote Sensing

In addition to ground-mapping, attempts have been made to map the Craters of the Moon lava flows by remote sensing, using LANDSAT and airborne radar images. Lefebvre (1975) used digital processing of LANDSAT images to delineate lava flows. Three properties of flow surfaces were recognized as contributing to the radiance values of flows on LANDSAT images: surface roughness, chemistry and mineralogy, and cover.

Differences in surface roughness enabled discrimination between aa and pahoehoe flows. Differences in surface chemistry and mineralogy and surface cover allowed delineation of pahoehoe flows of different ages. Lefebvre and Abrams (1977a, 1977b) later reported, however, that while radiance values of pahoehoe flows did show a general correlation with flow age, age relationships between several pairs of flows were misclassified when established using radiance data only.

Results of Lefebvre's (1975) study indicated that the Craters of the Moon lava field has had three or possibly four eruptive periods. Also, the enhanced LANDSAT images revealed, and field investigations substantiated, that the Blue Dragon-type lava flow crust occurs in a much larger area than reported by Murtaugh (1961).

Rothery and Lefebvre (1985) used a Milton Multiband Radiometer (MMR) to determine the bidirectional reflectance factor (BRF) of pahoehoe flow surfaces from the ground. The MMR was equipped with filters to simulate LANDSAT imagery. Flows known from other studies to be about 2,000, 4,000, 8,000, 10,000, and 12,000 years old were sampled. The researchers found that spectral response (BRF) was greatly increased by lichen cover, and, to a lesser extent, moss cover. Chemical weathering of the lava surface also increased BRF, possibly due to the development of a silica-gel coating, devitrification, or other processes over time.

On bare pahoehoe flows, BRF increased with chemical weathering. On older pahoehoe flows, moss and lichen cover augmented the spectral changes due to weathering. On flows older than about 8,000 years, however, lichen and weathering caused little further change, and cover by vascular plants and sediment contributed most to increases in BRF (Rothery and Lefebvre 1985).

The use of radar to detect fissure vents in the Craters of the Moon lava field also has been evaluated (Viglienzone and Greeley 1981, Martel 1984, Martel and Greeley 1984). X band and L band synthetic-aperture, side-looking airborne radar images were examined for surface texture characteristics. Researchers hypothesized that the changes from smooth to rough lava with increasing distance from a fissure vent would produce changes in gray tones on radar images, enabling location of fissure vents.

Differences in lava surface textures were most apparent in L band, cross-polarized images. In those images, however, near-vent Shelly pahoehoe and older pahoehoe flows, weathered or covered by a mantle of aeolian material, had identical backscatter characteristics. Thus, weak backscatter did not necessarily indicate proximity to a vent. Textural transitions in the lava were apparent in the radar images, but generally did not correspond to single flows. Juxtaposition of different flows, differential weathering of portions of flows, and other factors prevented tracing the flows to their sources (Martel, Martel and Greeley 1984).

Spatter cones and spatter ramparts were detectable in the X band radar images, indicating the location of fissure vents. But because not all fissure vents are accompanied by existing spatter cones, searching for spatter cones and ramparts would be an ineffective way to locate all fissure vents (Martel 1984, Martel and Greeley 1984).

Chemical Composition of Magma and Volcanic Rocks

Three types of magma have been identified in flows along the Great Rift (Kuntz et al. 1986a). One type, containing 45-48 percent silica ($Si0_2$), is represented by Kings Bowl and Wapi lava flows and Snake River Plain olivine basalts. A second, contaminated type of magma containing 49-64 percent silica and a third, fractionated type containing 44-54 percent silica were erupted from the Craters of the Moon lava field. The silica content of the Craters of the Moon lava flows changed with time from non-evolved lavas (greater than 52 percent silica) during early eruptive periods to evolved lavas (less than 52 percent silica) during later periods.

Strontium isotope ratios also indicate that Craters of the Moon lavas derived from Snake River Plain olivine tholeiite by the combined processes of fractional crystallization and crustal contamination. Strontium isotope ratios of Craters of the Moon basalts and associated latites (0.7080-0.7180 $^{87}Sr/^{86}Sr$) were higher than from the rest of the Snake River Plain (Leeman and Manton 1971). Blue Dragon lava was formed by the approximately 80 percent crystallization of Snake River Plain olivine tholeiite (Stone et al. 1970).

Stone et al. (1970) did not believe that contamination was responsible for Craters of the Moon lavas, except as a possible source of strontium 87, because similar lavas of different ages occur at Antelope Flat, Blackfoot River, and King Hill, on or near the Snake River Plain. However, xenoliths in Craters of the Moon lava are evidence that some contamination has occurred.

According to Kuntz et al. (1986a), most eruptive periods began with flows higher in silica and were followed by flows lower in silica. This trend within eruptive periods suggests that magma reservoirs are zoned vertically and replenished by relatively silica-poor magma, and that most eruptive periods began with removal of fractionated magma at the top of a reservoir and ended with removal of relatively silica-poor magma lower in the reservoir. Increased SiO_2 results in increased viscosity of liquid lava (Leeman et al. 1976, Kuntz et al. 1983).

The increased rate of volcanic output occurring between 7,000 and 2,000 years BP was attributed to the addition over the last 15,000 years of evolved lava to the constant supply of non-evolved lava (Kuntz et al. 1982).

Russell (1902) collected a sample of lava from the Craters of the Moon lava field and had it analyzed for 24 chemical compounds. It contained 51.4 percent silica. By comparing this sample with slag produced in iron-smelting furnaces, it was estimated that the lava probably would melt at 1,232°C. Highly liquid at that point, it would cool slowly through a highly viscous state before solidifying. According to Stone et al. (1970), Craters of the Moon lavas probably were liquid at 1,110-1,060°C.

Lava from the Craters of the Moon lava field is distinctly different from Snake River Plain basalts and ranges from the alkali- and phosphorus-rich ferrobasalts of pahoehoe and aa flows to the ferrolatites of blocky flows. The composition of nine Craters of the Moon lava samples ranged from 46.04 to 62.86 percent silica, 1.88 to 4.72 percent potassium oxide (K_2O), 0.15 to 2.28 percent phosphate (P_2O_5), and 16.39/3.89 to 8.39/0.21 total iron as ferrous oxide:magnesium oxide (FeO/MgO) (Stone 1969). Craters of the Moon lavas are unusually enriched in phosphate, total iron, alkalis, barium (Ba: 0.1-0.22 percent), gallium (Ga: 0.003-0.005 percent), yttrium (Y: 0.007-0.01 percent), zirconium (Zr: 0.05-0.09 percent), rare earth elements, and radiogenic strontium. They are extremely low in chromium (Cr) and nickel (Ni) and relatively low in vanadium (V) (Stone et al. 1970).

The results of a major-element analysis of 158 lava samples from the Craters of the Moon lava field were tabulated by Kuntz et al. (1985). The transition metal content of Craters of the Moon lavas was reported by Leeman et al. (1978).

Craters of the Moon lavas contain phenocrysts of andesine, olivine (Fo 50-10), plagioclase (An 60-40), brown clinopyroxene, titanomagnetite, ilmenite, and brown glass. Some contain orthopyroxene and apatite. Evolved basalts contain xenoliths and xenocrysts of corroded anorthoclase, plagioclase (An 55-15), green clinopyroxene, olivine (Fo 25-10), and zircon (Stone 1969, Kuntz et al. 1983, Leeman and Manton 1971, Leeman et al. 1976).

Xenoliths

Stearns (1931) noted that ejected rock fragments among cinders on cinder cones indicate that rhyolite and granodiorite underlie the basalt. Xenoliths from the Serrate Flow were identified as coarse-grained hypersthene quartz diorite.

Bullard (1971b) collected and examined xenoliths from the Serrate Flow and from the floor of North Crater. Most xenoliths consisted of gneissic material. In addition, two previously unreported types of xenolith were discovered at North Crater. One type was a brown, pumice-like material, commonly found in spatter on the crater walls and in blocks on the crater floor. The second type was pink rhyolite, of which two fragments were found on the east rim of the crater.

Matty et al. (1982) identified xenoliths found in the Devil's Orchard-Serrate flows as charnockite. One- and two-pyroxene granulites also were present.

Leeman (1979) analyzed the isotopic and trace element content of xenoliths from the Craters of the Moon lava field. The xenoliths suggested a deep Archean (early Precambrian) basement complex several hundred kilometers west of geologically similar surface outcrops in the northern Rocky Mountains.

Blue Dragon Basalt

The unusual color of the Blue Dragon lava was found by microscopic and spectrophotometric examination to be caused by abundant, partly oxidized titanium magnetite crystals in the lava's outer layers that reflect intense blue light (Faye and Miller 1973). A thin, siliceous film on the lava surface transmits and scatters the blue light. It was proposed that electron transfer from ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}) and probably from ferrous iron to the titanium ion (Ti^{4+}) causes the blue color (Faye and Miller 1973).

Miller (1969, 1970) determined that just prior to eruption, the source magma probably was confined at an elevated temperature and in a reducing environment. Ferrous iron content was high due to the presence of 2-3 percent phosphorus as a reducing agent. Upon eruption, Blue Dragon-type lavas immediately acquired a black, ferric oxide-silicate crust. The subcrustal lava formed chromophore groupings of Fe^{3+}-O-Fe^{2+}, which creates blue color in iron-bearing glass.

Secondary Minerals

Secondary minerals are present in spatter cones and lava tubes of Craters of the Moon National Monument. The secondary sulfate minerals gypsum, mirabilite, and jarosite were found in the Crystal Pit Spatter Cone (Stearns 1931, Peck 1974b). Gypsum crystals were present as a crust on cave walls and lava stalactites. Mirabilite deposits occurred as efflorescent crusts up to 15 centimeters thick. Jarosite occurred as a secondary crust on ferruginous ores and cracks in adjoining rocks. Thenardite and gypsum also were observed in other caves (Stearns 1931, Sanchez and Peck 1959, Peck 1962), and coralloid opal was found in Arco Tunnel (Peck 1962). Dake (1948) reported that kalinite was found by the monument caretaker, 67 meters deep in a crater. Mirabilite, gypsum, and thenardite from the Craters of the Moon lava field were identified by X-ray diffraction and differential thermal analysis by Karlo et al. (1980).

Stearns (1931) believed that the secondary minerals formed by condensation of mineralized volcanic gases. Peck (1974b) hypothesized that the gypsum and mirabilite were deposited from mineralized capillary ground water that seeped into the spatter cones, although the minerals' source was not ascertained.

Karlo et al. (1980) hypothesized that the mineral deposits were fumarolic in origin, but that the more soluble minerals went through solution, leaching, transport, and redeposition by ground water. They also hypothesized that jarosite remained from the original deposits while sulfates of sodium and magnesium were secondary minerals. Stearns (1931) noted that the yellow and brown stains along cracks in pahoehoe were caused by hydrous iron oxide, which had been converted from magnetite by steam at fumaroles.

FLORA

Although most of Craters of the Moon National Monument is covered by barren lava flows, it supports a surprising diversity of plant communities. Day and Wright (1985) identified, described, and mapped 26 vegetation types at Craters of the Moon National Monument (Table 2). Their report, based on aerial photographs and extensive ground surveys, lists 90 plant species that compose the various vegetation types.

Table 2. Vegetation types of Craters of the Moon National Monument and areas occupied by each type. From Day and Wright (1985).

Vegetation type	Area (ha)
1. Cinder gardens	484
2. Low density lava flows	12,525
3. Medium density lava flows	2,196
4. Mountain big sagebrush/bluebunch wheatgrass	1,122
5. Mountain big sagebrush/Sandberg bluegrass	2,527
6. Mountain big sagebrush/needle grass	315
7. Mountain big sagebrush/needle-and-thread/ cheatgrass	2
8. Mountain big sagebrush/Idaho fescue	98
9. Big sagebrush/cheatgrass	7
10. Complex of types 4 and 8	5
11. Three-tip sagebrush/Idaho fescue	41
12. Early low sagebrush/Idaho fescue	0.4
13. Low sagebrush/Sandberg bluegrass	126
14. Low sagebrush/Idaho fescue	26
15. Complex of types 13 and 14	15
16. Antelope bitterbrush	477
17. Antelope bitterbrush/Great Basin wildrye	85
18. Bluebunch wheatgrass/Idaho fescue	0.4
19. Bluebunch wheatgrass/Sandberg bluegrass	10
20. Great Basin wildrye	9
21. Limber pine/antelope bitterbrush (low total cover)	226
22. Limber pine/antelope bitterbrush (high total cover)	1,212
23. Limber pine/antelope bitterbrush (high density limber pine)	87
24. Douglas-fir/mountain snowberry	29
25. Upland quaking aspen	15
26. Riparian	30
Total	21,670

The first published checklist of the monument's plants contains a list and description of 69 vascular plant species (McElreath 1930). Wunner (1967) created a dichotomous key to 291 species of vascular plants found in the monument and described seven general vegetation types: Douglas-fir forest, riparian, sagebrush-bunchgrass, bare cinders, limber pine forest, shallow crevice, and deep crevice. The latter two types were found on recent pahoehoe flows. Urban (1968b) updated Wunner's list to include 304 plant species and published a popular field guide to plants of Craters of the Moon National Monument, which includes color plates (Urban 1971).

Plant Communities on Cinder Cones

The plant communities on the monument's cinder cones have long been of particular interest. Eggler (1941) recognized three cinder cone plant communities:

1. Pioneer community of herbs

2. Tree-dominated community, restricted to protected areas, primarily on north-facing slopes

3. Shrub-dominated community

Eggler found that plants on cinder cones were concentrated on northeast slopes, coinciding in winter with snow accumulations resulting from prevailing southwest winds. Soil measurements, however, showed little difference in available water between north and south sides of cones.

Eggler (1941) believed that direct effects of wind were unimportant factors in plant survival on cinder cones, but that wind increased water loss through transpiration and evaporation. On cinder cones supporting herbaceous plants, evaporation rates were 1.2 times higher on southwest than on northeast slopes. On northwest slopes, evaporation rates were 1.3 times higher in herbaceous communities than in pine communities at the same elevation.

Temperatures recorded 7.6 centimeters below cinder cone surfaces in June were equal to or higher than air temperatures for all hours of the day and night. Eggler (1941) speculated that these high soil temperatures could be fatal for some plants, especially seedlings.

Wunner (1967) thought that the combination of wind and exposure on southwest slopes results in less snow accumulating there than on opposite-facing slopes. These differences in snow accumulation and wind in turn helped produce the monument's patterns of vegetation. Other factors Wunner mentions are lava flows (evidenced by tree molds), logging, mining, grazing by livestock and wildlife, dwarf mistletoe "control" programs, and fire. Because of the monument's irregular topography, fires leave islands of unburned vegetation that are sources of seed for reinvasion of burned areas.

Limber pine seedling survival on an area of North Crater being "invaded" by pines was less than 3 percent (of 105) between late June and late August 1938 (Eggler 1941). Both Eggler (1941) and Day (1985) found that limber pine seedlings often grew in clumps, suggesting seed dispersal by animals such as Clark's nutcrackers (*Nucifraga columbiana*) and red squirrels (*Tamiasciurus hudsonicus*). Day (1985) found that clumped and isolated limber pine seedlings had similar survival rates. Survival rates of limber pines seedlings growing in bare areas and in the canopy region of *E. ovalifolium* also were similar, but were lower for seedlings in the canopy region of other plants.

Changes in Plant Communities

In a long-term study of vegetation change at the monument, Wright and Bunting located 90 photographs taken between 1920 and 1965 that depict plant community mosaics at the monument. The photos cover an area of about 6,000 hectares. In 1986, each of the scenes was rephotographed as exactly as possible. Quantitative analysis of the changes in plant community composition and structure was done using a zoom transfer scope and digitizer. This technique enabled an exact computation of the changes in each of the identified vegetation types.

The study's initial results (Wright and Bunting 1987) show that the mixed shrub communities have been remarkably stable over time. The areas occupied by the shrub communities showed no evidence of being influenced by fire, browsing, or human disturbance. On the other hand, Wright and Bunting noted significant increases in the numbers of limber pines and in the areas occupied by aspen stands. The changes in the numbers of limber pines were, however, biased by the dwarf misteltoe control program (decribed later), in which many trees were removed.

Succession

The lack of disturbance and the existence of well-defined lava flows and cinder cones have made Craters of the Moon National Monument an ideal site for the study of primary plant succession. Two major studies are described here.

Succession on Lava Flows

Plant succession at Craters of the Moon National Monument was first studied on pahoehoe flows from 1936 to 1938 (Eggler 1941). Eggler found some soil on even the youngest flows. Only lichens grew on flow surfaces, but vascular plants were established in depressions.

Eggler identified four vegetation habitats of young pahoehoe flows:

1. Xeric, bare flow surface: pioneer plants are lichens (this was the most extensive habitat)

2. Joints and crevices containing thin soil deposits and supporting two species, *Alopappus nanus* and *Chrysopsis hispida*

3. Shallow crevice: soil accumulations of 2.5-7.6 centimeters with crevices too shallow for a mature shrub to grow with its aerial portions below the flow surface; predominant species are *Drymocallis pseudorupestris, Penstemon deustus, Pteryxia terebinthina* var. *foeniculacea, Stipa occidentalis, Stephanomeria myrioclada,* and *Erigeron trifidus*

4. Deep crevice: deep enough (at least 0.6 meters) for a mature shrub to grow with its aerial portions below the flow surface; seven species are characteristic of this habitat, the first five listed being exclusive to deep crevices, *Philadelphus lewisii, Sericotheca glabrescens, Brickellia grandiflora* var. *minor, Woodsia scopulina, Dryopteris filix-mas, Chamaebatiaria millefolium, Pinus flexilis*

The most important factor determining vegetation on a lava flow is the amount of soil (Eggler 1941). Eggler suggested that after soil fills crevices, it deposits in an even layer over the flow surface. As this occurs, plants are eliminated first from deep crevices, then from shallow crevices, then joints, and they eventually are replaced by a grass-sage climax community dominated by *Artemisia tridentata, Purshia tridentata, Chrysothamnus nauseosus, Eriogonum microthecum, E. heracleoides,* and *Leptodactylon pungens* (Eggler 1941). Stearns (1931) noted that pine trees grew out of small cracks on otherwise apparently barren lava surfaces and assumed that the soil deposited in the cracks was wind-transported dust rather than weathered lava.

Plant species composition within study plots on six pahoehoe flows of different age was used to characterize primary succession. Flow age was based on Stearns (1930). Eggler (1941) found 52 plant species which he placed into three categories:

1. Pioneers (14 species), which increase for a time and then decrease as flow age increases (e.g., limber pine)

2. Climax species (14), which increase with flow age and reach their greatest densities on the oldest flows (e.g., sagebrush [*Artemisia tridentata*] and rabbitbrush [*Chrysothamnus nauseosus*])

3. Incidental species (24), which exhibit no apparent successional trends

The number of species found on each flow and the total number of individual plants per 0.1 hectare increased with flow age; the oldest flow (Silent Cone Flow) had 2.3 times as many species and 28 times as many individual plants as the youngest flow (Indian Tunnel Flow).

At Craters of the Moon National Monument it appears that aa flows take longer to reach the climax stages of primary succession than pahoehoe flows of similar age. Eggler (1941) attributed this difference to the greater amount of time required for soil to accumulate and eventually cover the irregular surfaces of aa flows. Limber pines were more abundant on aa than pahoehoe flows, but in both cases they occurred where water collected, especially where the trees received protection from the wind.

Plant Succession on Cinder Cones

Day (1985) attempted to describe the successional sequence of vegetation and soils on the monument's east-facing cinder cone slopes ranging from 2,220 to 12,600 years old. On areas with the least soil development, the initial colonizers were *Eriogonum ovalifolium* var. *depressum* and *Phacelia hastata*. These two species were negatively associated with their own canopy regions and with the two later-successional species, *E. umbellatum* and *Pinus flexilis*. All major species on these sites were positively associated with the inner canopy of *E. ovalifolium. Phacelia* may show this association due to higher moisture under *E. ovalifolium* and/or because wind-blown *Phacelia* seeds accumulate under *E. ovalifolium. E. ovalifolium* also appeared to enhance the establishment of all other major species on less-developed sites by modifying the microenvironment. These observations supported the facilitation model of primary succession, though Day (1985) concluded that other mechanisms were also involved in succession.

On the same site, soils under the initial colonizers *E. ovalifolium* and *Phacelia* had higher levels of moisture, nitrogen, and available phosphorus than soils under bare areas or under the later successional species *E. umbellatum* or *Pinus*. Day (1985) speculated that this was due to greater accumulations of fine material and to lower nutrient absorption rates by initial colonizers than by later-successional species, and possibly also to differences in microbial populations, although soil microbes were not measured.

Initial colonizers were common in mule deer (*Odocoileus hemionus*) tracks in cinder garden communities. Day hypothesized that this phenomenon may have been due to moisture, seeds, and organic matter accumulating in the depressions. Both Eggler (1941) and Limbert (1924) reported similar findings.

On more developed sites dominated by woody species, associations among plant species were inconsistent. Day (1985) thought that this may have been due to differences in soils caused by buried horizons as well as to other factors. A chronosequence of vegetation and soils could not be developed because past A horizons were buried in soil profiles at most sites. Kuntz (1984), however, was skeptical that these were actually A horizons because each cinder cone in the monument probably was formed during one relatively short eruptive period that would not have allowed time for soil to develop below the current cone surfaces. Kuntz speculated that what appeared to be buried A horizons might actually be layers of ash deposited during cinder cone formation.

Plant Succession in the North End

In 1966 and 1967, Urban (1967a, 1967b) began what was intended to be a long-term monitoring of secondary plant succession in a roadbed of the Martin Road closure area in Craters of the Moon National Monument. The regional climax was determined to be *Artemisia arbuscula* and *Festuca idahoensis*. Ten permanent quadrats were established in the roadbed. Plant coverages were recorded within the quadrats and photographs of each quadrat were taken in 1967.

Plant Ecology Studies at the Carey Kipuka

The Carey Kipuka is surrounded by aa lava flows and appears to have experienced limited grazing. In 1955, the Carey Kipuka was identified as a potentially unique ecological area by scientists interested in native sagebrush grasslands of Idaho. At the time, the 73-hectare kipuka was believed to be the largest undisturbed expanse of rangeland in Idaho, making it valuable for research and useful as a standard in range condition classifications (Henderson and Murie 1958, Tisdale and Fosberg 1958, Murie and Cole 1959, Yingst and Handy 1961, Tisdale et al. 1965).[1] Researchers from the University of Idaho (UI) and the USDA Soil Conservation Service (SCS) began studies at the kipuka in 1956 and 1958, respectively (Yingst and Handy 1961). To preserve the area for scientific study, the Carey Kipuka was added to Craters of the Moon National Monument in 1962 (Tisdale et al. 1965).

In one of the first studies relating the kipuka's vegetation and soils, SCS scientists identified and described six soils of the Carey Kipuka, all members of the Chestnut great soil group:

1. Tetonia silt loam, deep over basalt
2. Eagle Cone very stony silt loam, moderately deep over basalt
3. Carkip silt loam
4. Goodington silt loam
5. Gooding loam, deep over basalt
6. Bancroft silt loam, deep over basalt cinders

The soils formed from loess, basaltic ash, and basaltic cinders (Hugie et al. 1964). Because the kipuka appeared to be pristine, it was assumed that differences in its plant communities (e.g., plant species composition, size of plants, and total herbage production) were caused by differences in soils. Aside from studies at the Carey Kipuka, no soil survey has been completed at Craters of the Moon National Monument.

Passey et al. (1964) measured air-dry herbage, species composition, and soil moisture associated with three soils of the Carey Kipuka: Tetonia silt loam, Goodington silt loam, and Bancroft silt loam. Tetonia silt loam was the most productive soil, followed by Bancroft silt loam and Goodington silt loam. Total herbage production and species composition varied greatly between years and between soil taxonomic units in the same year. Production of grasses and forbs fluctuated more widely than production of shrubs and annuals. These fluctuations did not appear to be cumulative, and therefore were not believed to permanently alter the plant communities.

Correlations indicated that precipitation from October through March was more important for herbage yield than was precipitation during other periods of the year. Herbage production also was closely correlated with available soil moisture at the end of March, evapotranspiration, and total water used in herbage production (Passey et al. 1964).

The vegetation and soils of the Carey Kipuka also were studied for several years on permanently marked stands by UI scientists (Tisdale et al. 1965). Three major community types were recognized:

1. *Artemisia tripartita/Festuca idahoensis,* associated with moister and/or cooler areas on north and east slopes and with slight depressions and relatively deep, fertile soils
2. *Artemisia tridentata/Festuca idahoensis/Agropyron spicatum,* associated with drier south and west slopes
3. *Artemisia longiloba/Festuca idahoensis/Stipa thurberiana,* associated with a distinctive clay B horizon

None of the sites studied by Eggler (1941) had soils or vegetation as mature as those of the Carey Kipuka.

Dwarf Mistletoe

In 1961, a dwarf mistletoe control program was initiated at Craters of the Moon National Monument. The first phase of the program included a survey of dwarf mistletoe-infected trees in limber pine stands and a control experiment to estimate costs of pruning and felling the limber pines (Henderson 1961a). Surveys of

[1] Although the kipuka has remained undisturbed in the intervening 32 years, recent, unpublished observations by Stephen Bunting and R. Gerald Wright of the University of Idaho indicate that the area suffers from exotic species encroachment.

0.04-hectare plots in 30 limber pine stands indicated that infection was well established in all stands (Henderson 1961b). It was recognized that in some areas, control would result in removal of more than 90 percent of the mature trees. Artificial planting and seeding was proposed for areas where natural reproduction was considered inadequate (Henderson 1961a).

In July 1962 (Merriam 1962), the NPS regional director advised that the dwarf mistletoe control project "should be carried out as experimental in nature" and recommended that two untreated plots be permanently established, one with a heavy infection and one without infection. The regional director also recommended that the effectiveness of the control program be evaluated at three-year intervals for 25-50 years. His recommendations were not carried out.

More than 6,000 heavily infected trees were felled or poisoned in the dwarf mistletoe eradication program during 1962 and 1963. Although the project developers anticipated that 2,000 seedlings would be available for planting in 1963, only 52 seedlings had been raised by March 1964 (Davis 1964). Limber pine regeneration was therefore limited to natural processes.

In 1966 and 1967, Urban (1968a) studied the dwarf mistletoe problem with respect to the extent of infection before and after the control program of 1961-1963 and the changes in plant communities resulting from control efforts. With the exception of five uninfected stands, he found that the dwarf mistletoe infection was nearly as widespread as the limber pines. Distribution patterns suggested that the infection spread from west to east, the direction of prevailing winds.

Several isolated infections were found, which is reportedly unusual for dwarf mistletoe. The isolated infections may have been caused by wind-borne seeds, relict infection from ancient stands, or biotic vectors such as mourning doves (*Zenaida macroura*) or mountain bluebirds (*Sialia currucoides*), both of which were observed eating dwarf mistletoe berries (Urban 1968a).

The percentages of infected trees in limber pine stands were lower in 1967 than in the pre-eradication survey of 1961, due to mechanical removal of prunable infections and felling and poisoning of heavily infected trees in 1962 and 1963. Residual infections were found in all stands treated in the eradication program. Residual infections were reportedly difficult to control in the monument's uneven-aged stands. Furthermore, increased light intensity resulting from host removal was believed to stimulate growth of residual dwarf mistletoe shoots. The 1967 survey found an increase since 1961-1963 in the percentage of trees with light to moderate infections (Urban 1968a).

Taller trees were more heavily infected. Assuming tree height is a reliable index of canopy cover, this is a result of their having greater surface areas for intercepting dwarf mistletoe seeds. Infection levels were higher on cinder cones than on pahoehoe or aa lava flows. Although cinder cones had higher densities of limber pines, density was not correlated positively with infection intensity. No explanation was found for higher infection levels on cinder cones, though Urban (1968a) suggested that the cones' slopes may have had an effect.

No significant effect of different infection intensities on radial growth of the slow-growing limber pines was found. Urban (1968a) speculated that environmental conditions at the monument (e.g., precipitation) may have played a more important role in determining annual growth rates.

Urban (1968a) took core samples from trees showing signs they had been infected when very young. Tree-ring counts from these samples indicated that the trees had been initially infected at least 209 years prior to the study.

Urban (1968a) considered that the limber pine plant community was a seral stage in plant succession towards a climax sagebrush community, because the limber pines apparently were unable to successfully reproduce once a shrub understory was established. He contended that removal of limber pines from stands with a closed understory for mistletoe control accelerated normal succession, because the few remaining seedlings would be unlikely to reproduce given the unfavorable shrub:tree cover ratio. Pruning the limbs of trees was expected to increase the possibility of successful limber pine regeneration.

Urban (1968a) believed the conditions for tree regeneration were favorable on sites where shrub understories were present but not dominant. In 1967, however, no seedlings were found on these sites. Large seedling crops were found on sites in the pioneer stages of succession. Here tree removal appeared to effectively retard normal succession by removing mature pines that contributed to soil development.

No research on dwarf mistletoe has been conducted in Craters of the Moon National Monument since Urban's (1968a) study.

FAUNA

Invertebrates

A comprehensive inventory of insects was completed during 1964-1967 (Horning 1966, Horning and Barr 1970), using standard collection methods at 12 stations within the monument. Insects representing 20 orders, 248 families, 1,144 genera, and 2,064 species and subspecies were found. More than 30 species were new to science. The three most abundant orders were Hymenoptera (705 spp.), Diptera (521 spp.), and Coleoptera (324 spp.).

Numbers of species collected at a station were related to the type and age of the geological substrate and to the variety and abundance of plants. The Little

Cottonwood Creek station supported the greatest number of insect species. Within lava habitats, old cinder cones supported the most species, while young aa flows supported the fewest. Several plant species were especially important to insects: *Chrysothamnus nauseosus, C. viscidiflorus, Chamaebatiaria millefolium, Phacelia hastata,* and *Pinus flexilis* (Horning 1966, Horning and Barr 1970).

In reviewing the invertebrate fauna of volcanic caves in western North America, Peck (1973) mentioned six families, five genera, and four species found in lava tube caves of Craters of the Moon National Monument. One insect of special interest in this study was the Idaho lava tube beetle (*Glacicavicola bathyscioides*). This species, discovered by Westcott (1968), is known only from lava tube caves in Idaho. How the beetle colonized the monument's caves following recent volcanic activity is unknown.

Fifty-two lava tube beetles were captured at Craters of the Moon National Monument, and their habits were observed in laboratories (Peck 1974a). The species appeared to be a scavenger of arthropod remains. The beetles lived at least two years in captivity.

Youtie (1986) studied the relationships between Great Basin wildrye (*Elymus cinereus*) and its associated insect fauna with special reference to the wheat stem sawfly (*Cephus cinctus*) at Craters of the Moon National Monument and at the Idaho National Engineering Laboratory. The Craters of the Moon study site was an 8.5-hectare stand of Great Basin wildrye at the mouth of Cottonwood Creek Canyon. Forty-five insect species were found on the monument's Great Basin wildrye. The majority were oligophagous (restricted to feeding on grasses). In addition, five parasitoid species were reared from insect hosts.

At Craters of the Moon, 62-73 percent of the Great Basin wildrye plants and 22 percent of the tillers were infested with sawflies. Adult sawflies emerged from wildrye culms concurrent with the emergence of inflorescences from grass sheaths. Eggs were deposited in the larger grass stems. Seed weight and number of seeds per floret were significantly lower in culms containing sawfly larvae. Germination rates of seeds from sawfly-infested and noninfested culms were the same (Youtie 1986). The phenology of sawflies and wildrye was three weeks later at the monument than at INEL.

Amphibians and Reptiles

The wildlife checklist for Craters of the Moon National Monument (Anon. 1982), which is based on observations by personnel and visitors at the monument, lists one amphibian and seven reptiles. These are the western toad (*Bufo boreas*), sagebrush lizard (*Sceloporus graciosus*), short-horned lizard (*Phrynosoma douglassii*), western skink (*Eumeces skiltonianus*), rubber boa (*Charina bottae*), racer (*Coluber constrictor*), Great Basin gopher snake (*Pituophis melanoleucus*), and western rattlesnake (*Crotalus viridus*).

Four reptilian species were captured in a study of the flora and fauna of kipukas of Craters of the Moon lava field (Anderson and Lovejoy 1979). They were the sagebrush lizard, western skink, Great Basin gopher snake, and western rattlesnake.

Guyer and Linder (1985a, 1985b) studied short-horned and sagebrush lizards in an area at INEL dominated by big sagebrush (*Artemisia tridentata*), rabbitbrush (*Chrysothamnus nauseosus*), halogeton (*Halogeton glomeratus*), and squirreltail grass (*Sitanion hystrix*). Densities of both species were estimated at 14 individuals per hectare (Guyer and Linder 1985a).

In both lizard species, adult females were significantly larger than adult males. This was attributed to continued growth of adult females during the second year of life, but not of males. This sexual dimorphism may reflect a long-lived iteroparus reproductive strategy.

Over-winter survival was high for adults of both species and for juvenile sagebrush lizards, but low for juvenile short-horned lizards. Adults of both species emerged in mid-April and began hibernation in late August to early September. Young of the year appeared in early August.

The sagebrush lizard apparently used rodent burrows overnight, resulting in its having more uniform cloacal temperatures throughout the day than the short-horned lizard, which remained above ground overnight. Mean daytime cloacal temperatures were approximately 33°C for both species (Guyer and Linder 1985b). The lizard's principal prey was ants (*Pogonomyrmex*).

Birds

Stearns (1928a) listed 24 avian species reported to inhabit Craters of the Moon National Monument. Carter (1970) compiled an annotated list of the monument's birds, which was based on personal field observations supplemented by records on file at the monument (Appendix 2). Fitcher (1960) observed a red-headed woodpecker (*Melanerpes erythrocephalus*) near Devil's Orchard. Although no specimens of this species had previously been collected in Idaho, it had been included in Stearns's (1928a) list of birds.

Raptors

Raptors at INEL were surveyed from a car from November 1974 to May 1976. The most abundant raptors were the American rough-legged hawk (observed mostly in mid-October to mid-April), American kestrel (observed mostly in April through September), golden eagle, northern harrier, and prairie falcon (Craig 1978). In 1981-1982, the survey was repeated, and eagle and buteo abundance was found to be much higher. This was attributed to an increase in black-tailed jackrabbits between the two surveys. Raptors that increased were the

American rough-legged hawk, ferruginous hawk, golden eagle, and bald eagle. In 1982, nests of the golden eagle, ferruginous hawk, red-tailed hawk, and Swainson's hawk were more numerous than in 1974-1976 (Craig et al. 1984). Active nests of ferruginous hawks at INEL declined from 11 in 1972 to seven in 1975 (Powers and Craig 1976).

Individually marked rough-legged hawks at INEL occupied well-defined but overlapping winter ranges. Range size and shape were determined largely by the distribution of utility poles. The poles were used for hunting and often were paralleled by roads providing rabbit carrion, which made up a large percentage of the hawks' diet (Watson 1986).

Nesting American kestrels at INEL were found to begin incubation early to mid-May. Mean hatching date was 25 June, and mean fledging date was 24 July. Based on remains found at kestrel nests, birds made up the majority of the prey biomass (Craig and Trost 1979).

Nesting merlins were observed in Blaine and Butte counties in 1975 and 1977, respectively. These were the fourth and fifth records of merlins nesting in Idaho, and the only records since 1913 (Craig and Renn 1977).

Nesting long-eared owls at INEL have been found to begin laying eggs from mid-April to late May. Mean hatching and mean fledging dates were 25 May and 14 July, respectively. In 1976, 17 of 18 nests were in old, black-billed magpie nests. Ninety-seven percent of the long-eared owls' prey were small mammals. Northern pocket gophers (*Thomomys talpoides*) accounted for 42.8 percent of the biomass in the owls' diet (Craig and Trost 1979). Prey remains in long-eared owl castings collected at a communal roost in July 1982 indicated that microtenes and *Peromyscus* were the most important prey species, accounting for 43.3 percent of biomass (Craig et al. 1985).

Sage grouse

In 1978-1979, 51 sage grouse leks were found on or near INEL (Connelly et al. 1981). Sage grouse used both natural clearings and disturbed areas, including gravel pits and burned areas. Their use of disturbed sites suggested that there were insufficient natural clearings in some parts of INEL (Connelly et al. 1981, Gates 1985).

Mourning doves

Mourning doves are present at INEL from late April to mid-September. Food habits of mourning doves in sagebrush-dominated areas were determined by analyzing 223 crops. Halogeton and Indian ricegrass (*Oryzopsis hymenoides*) made up 48 percent of the crop contents' mass. Wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), and oats (*Avena sativa*) made up 19 percent of the mass. Only 11 plant species were commonly eaten, with the majority found mostly in agricultural or disturbed areas. Nevertheless, the sagebrush ecosystem may be important for nesting (Markham and Trost 1986).

Passerines

Sage thrashers, sage sparrows, and Brewer's sparrows are the three passerine species restricted to sagebrush habitat in southeastern Idaho and have been studied extensively at INEL (Reynolds and Rich 1978, Reynolds 1981). Sage thrasher territories averaged 1.14 hectares in 1976 and 1.86 hectares in 1977. Ninety-five percent of territorial male sage thrashers obtained mates and nested. Thrashers nested on the ground under sagebrush or in sagebrush branches. The distance from the nest to the top of a sagebrush plant was the same for ground nests and for elevated nests, suggesting that nest sites may be selected based on the volume or density of material shading or covering the nest.

Sage thrasher clutch size averaged 3.5 (range 1-5). Average incubation was 15 days, and the average nestling period was 12 days. Some thrashers nested twice in one season. Sixty-nine percent of nests were successful (fledged at least one young). The probability of nesting success (the probability that an egg laid would produce a fledged young) was 0.45 (Reynolds 1981).

Sage sparrow territories averaged 0.81 hectares for males that obtained mates (53 percent) and 0.70 for males that did not obtain mates. Sage sparrows nested in the canopy of sagebrush plants. Clutch size averaged 2.8 (range 2-3). Average incubation was 14 days, and average nestling period was 10 days. Fifty-six percent of nests were successful; the probability of nesting success was 0.40 (Reynolds 1981).

Winter and Best (1985) compared nest placement by sage sparrows in unburned (1982) and burned (1983) sagebrush habitat. In 1982, sagebrush cover was 26.1 percent, and all sage sparrow nests ($n = 34$) were placed in sagebrush. After the burn (1983), sagebrush cover was 13.3 percent, and 21 percent of nests ($n = 29$) were built in depressions under sagebrush plants or within bluebunch wheatgrass (*Agropyron spicatum*, 1 nest). This may have been due to a requirement for a minimum amount of vegetation above the nest, as hypothesized for sage thrashers.

Brewer's sparrow territories averaged 0.52 hectares. Only 23 percent of males nested successfully. Brewer's sparrows nested about 10 days later than sage thrashers and sage sparrows. Nest sites were similar for all three species, which may account for the low percentage of male Brewer's sparrows that nested successfully. Brewer's sparrow nests were built in sagebrush canopies, and generally were more toward the outer branches than were sage sparrow nests. Average clutch size was 3.4 (range 3-4). Incubation and nestling periods averaged 11 and 9 days, respectively. Fourteen percent of nests were successful; probability of nest success was 0.09 (Reynolds 1981). During Reynolds's (1981) study, loggerhead shrikes were present on the study area in 1977, but not in 1976.

Between 1976 and 1977, density of all passerine nests (except shrike nests) decreased from 29 to 14 nests per 8 hectares, and successful nests decreased from 76 percent to 7 percent. Although it could not be proved that shrikes caused the decreases, shrikes were observed killing two sage sparrows and two Brewer's sparrows and unsuccessfully attacking sparrows and sage thrashers 25 times. Shrikes were also seen carrying away nestlings of other species and were believed to be responsible for predation at other nests. Two shrike nests fledged seven and nine young (Reynolds 1979).

Peterson et al. (1986) studied the growth of nestling sage and Brewer's sparrows at INEL. The variation in the growth of sage sparrows was accounted for by differences among years, periods of the breeding season, brood sizes, weather, and ectoparasites. These variables did not explain Brewer's sparrow growth.

Seasonal detectability profiles can be used to interpret census results for species such as the Brewer's sparrow that exhibit marked changes in conspicuousness during the breeding period (Best and Petersen 1985). Seasonal changes in the detectability of Brewer's sparrows and sage sparrows were examined at INEL by marking individual birds, mapping their territories, and counting birds by the spot-map method. It was found that seasonal observations varied significantly for Brewer's sparrows, but not for sage sparrows. Sage sparrows arrived at their breeding territories in pairs, while male Brewer's sparrows arrived before females. This resulted in Brewer's sparrows being more conspicuous early in the breeding season than after they paired. In fact, observations made early in the season indicated that the Brewer's sparrow population was 180 percent of the size determined by territory mapping.

Best and Petersen (1985) also found that breeding phenology for both sparrow species was three weeks later in 1982 than in 1981. This was presumed to be related to colder temperatures in 1982.

Mammals

Early explorers in the Craters of the Moon area reported wildlife sightings (e.g., Russell 1902, Limbert 1924, Stearns 1924, 1928a). Many of the accounts were vague and incidental to other work, and none included a comprehensive list of species present in the area.

Blossom (1936) compiled a mammalian species list for Craters of the Moon National Monument based on field identification and reports by local residents. Newman (1958) listed 19 mammal species present at the monument.

The monument's mammals were systematically surveyed in 1967-1968 (Fuller 1969). Trapping grids were placed in 18 habitats for a total 2,222 total trap nights. A species list was compiled from the trapping results and from observations and previous records, including superintendent's monthly reports. Appendix 3 lists mammals of Craters of the Moon National Monument by various reports. A project is underway through the UI Cooperative Park Studies Unit to survey the small- and medium-sized mammals at the monument and to develop systematic methods to monitor species presence and abundance.

Bats

Of the six bat species recorded at Craters of the Moon National Monument, only the small-footed myotis and Townsend's big-eared bat hibernate in lava tube caves of the Snake River Plain. The little brown myotis, long-eared myotis, big brown bat, and hoary bat are migratory.

Hibernating bats were found December 1984-January 1985 in lava tube caves at INEL and in Arco Tunnel at Craters of the Moon National Monument (small-footed myotis only). Temperatures within bat-containing caves ranged from -1.2 to 7.0°C, and humidity ranged from less than 43 percent to 100 percent. Small-footed myotis were found in tiny pockets and crevices near the highest parts of cave ceilings, in temperatures ranging from 1.5 to 5.5°C. Townsend's big-eared bats hung in open areas of the caves, in air temperatures from 2.2 to 7.0°C. In hibernacula of both bats, humidity ranged from 65 to 100 percent (Genter 1986).

Rodents

Halford (1981) trapped rodents on a burned and an unburned portion of sagebrush habitat at INEL. The kangaroo rat was the only one of six species captured that was more abundant in the burned area; it was not captured in the unburned area. In both areas during late May, deer mouse diets contained 90 percent insects.

Groves and Keller (1984) compared reproductive characteristics and weights of montane voles at INEL. Sixty-five percent of males and 12 percent of females had hip glands. Hip glands were positively associated with sexual maturity and body weight. The hip glands were suspected to be important in territorial defense and individual recognition, as well as in social interactions.

Lagomorphs

MacCracken and Hansen (1982a) determined from analysis of fecal pellet accumulations that abundance of black-tailed jackrabbits and Nuttall's cottontails was positively related to biomass of herbaceous vegetation at INEL. Both species were more numerous in areas that had not been grazed by livestock for at least 25 years. Cottontails occupied areas with a higher biomass of forbs than grasses and with abundant rock outcrops. Jackrabbits occurred in areas with a higher biomass of grasses than forbs (MacCracken and Hansen 1982a). Jackrabbit density was positively correlated with grass cover in summer. Jackrabbits were believed to feed in grassy areas at night and retreat to shrub cover during the day (Johnson and Anderson 1984).

Microscopic analysis of pellets indicated that black-tailed jackrabbits consumed 43 percent grasses, 10 percent forbs, and 46 percent shrubs in spring-summer and 9 percent grasses, 6 percent forbs, and 85 percent shrubs in fall-winter. Important plant species were wheatgrasses (*Agropyron* spp.), bluegrasses (*Poa* spp.), sedges (*Carex* spp.), halogeton (*Halogeton glomeratus*), common winterfat (*Eurotia lanta*), and big sagebrush (*Artemisia tridentata*).

Nuttall's cottontails consumed 78 percent grasses, 11 percent forbs, and 11 percent shrubs in spring-summer and 22 percent grasses, 16 percent forbs, and 62 percent shrubs in fall-winter. Plant species important to cottontails included wheatgrasses, needle-and-thread (*Stipa comata*), sedges, milkvetch (*Astragalus* spp.), bluebells (*Mertensia* spp.), pussytoes (*Antennaria* spp.), common winterfat, big sagebrush, and saltbush (*Atriplex* spp.). Dietary overlap of the two lagomorphs was 71 percent in fall-winter and 56 percent in spring-summer (MacCracken and Hansen 1984).

Black-tailed jackrabbit populations in the northern Great Basin are cyclic, reaching peak densities at approximately 10-year intervals. During a peak in 1981, the impact of jackrabbits on vegetation at INEL was examined using rabbit-proof exclosures. Total plant cover was significantly decreased on open plots compared with exclosures, and most of the above-ground portions of common winterfat and green rabbitbrush (*Chrysothamnus viscidiflorus*) were completely eaten in the winter of 1981-1982. By July 1982, however, winterfat and rabbitbrush biomass was the same on open and exclosure plots, due to compensatory regrowth of the two shrubs (Anderson and Shumar 1986).

The food habits of bushy-tailed woodrats and Nuttall's cottontails at INEL were compared by microscopic analysis of fecal pellets. Cottontail pellets contained mostly grasses. Wheatgrasses, needle-and-thread, Indian ricegrass (*Oryzopsis hymenoides*), cheatgrass brome (*Bromus tectorum*), bluegrasses, and bottlebrush squirreltail (*Sitanion hystrix*) accounted for 58 percent of plant fragments. Woodrat pellets contained mostly forbs, with pricklypear (*Opuntia polycantha*) making up 54 percent of plant fragments. Vetches (*Astragalus* spp. and *Vicia* spp.) and Munro globemallow (*Sphaeralcea munroana*) also were important components of both species' diets and accounted for most dietary overlap. Plant species composition was similar for cottontail pellets collected in woodrat dens and at nonden sites, indicating that woodrats had little influence on the diets of cottontails inhabiting their dens (Johnson and Hansen 1979a).

Mule Deer

The mule deer is the only vertebrate species that has been intensively studied at Craters of the Moon National Monument. Concern by monument personnel that portions of the range were over-browsed between the mid-1950s and mid-1960s prompted the first major mule deer study in the monument, from April 1967 to January 1968 (Ritchie 1968). In that study, thirty-three deer were captured in the lower half of Little Cottonwood Creek drainage and marked with ear tags and neck bands; six were fitted with radio transmitters. Marked deer were relocated 386 times. Also, tracks were counted along the north shoulder of Highway 93-A (Ritchie 1968).

Following that study, little attention was paid to the monument's mule deer until a series of studies on population dynamics and habitat use was conducted between 1980 and 1982 by Griffith (1983). In those studies, one hundred deer were marked and released, and their life histories were followed. Twenty of the deer were equipped with radio transmitters.

Population. Based on the reports of early workers at the monument, hunting patrol counts, and monthly reports, the monument's mule deer population appears to have increased between the monument's establishment in 1924 and the mid-1960s (Ritchie 1968). Prohibition of livestock grazing and hunting were believed to have been largely responsible for the increase.

Mule deer were counted four times during September and October 1967. The ratio of marked to unmarked deer was used to estimate the total population size as 335 deer. Ninety-five percent confidence limits on the population estimate were 181 and 489, however, 290 deer were observed in one count (Ritchie 1968).

Assuming a population size of 335 in October, the herd composition was 48 bucks, 125 does, and 162 fawns. Given the high productivity of the herd—48.5 percent fawns in October—and its apparently low mortality, Ritchie (1968) assumed that dispersal was the primary population regulating mechanism in the Craters of the Moon National Monument deer herd.

Griffith (1983) estimated the total population size during late August and early September 1980, 1981, and 1982 to be 478, 515, and 351, respectively. The average sex/age composition was 40 percent fawns, 41 percent does, 8 percent yearling males, and 11 percent adult males. Griffith thought that the deer population was not rapidly increasing. Griffith thought that along with dispersal, hunting was a major control on the population. During each year of the study, hunters killed an estimated 15.1 percent of the population. In addition, average winter mortality was 34 percent of fawns, 37 percent of does, 25 percent of yearling males, and 27 percent of adult males. Three percent of the population was killed in vehicle accidents. Seventy percent of these road kills occurred during August and September when deer summering in the north end of the monument crossed the highway to forage on visitor center lawns and drink from sprinkler overflows.

Griffith (1983) found that breeding activity peaked during the first half of November. Ritchie (1968) found that fawning began during the last few days of May 1967, continued 4-6 weeks, and peaked approximately 15 June. During Griffith's study (1983), fawning peaked during the last week of May and first week of June. Griffith (1983) noted that limber pine stands appeared to be favored fawning habitat in southern areas of the monument. Fawn survival to 5 months was 66-86 percent and was 22 percent lower during a summer-drought year (1981) than during the previous wet year. Net fawn production surviving to fall was 1.34 fawns per adult doe.

Spring and Summer Movements. Ritchie (1968) found that the herd moved into the north end of the monument (north of the highway) in mid-April 1967 and divided into two groups in spring. One group remained in the north end of the monument and was relatively sedentary. By early May, the other group had moved into the southern portion of the monument as far as Fissure Butte. These deer made a 6.4- to 12.9-kilometer migration back to the north end, which contains the only open water in the monument, during late July and early August, the hottest and driest part of the year. Presumably, the mid-summer migration was due to insufficient available water in browse plants. There was evidence that some deer made daily nocturnal movements between the monument's north and south ends (Ritchie 1968).

During late spring and fall, deer were believed to obtain sufficient water from their food plants. In October, some deer moved from the north end to the south end of the monument. They were believed to be the same deer that ranged in the area earlier in the year (Ritchie 1968).

Griffith (1983) reported similar seasonal movement patterns. In the spring, about 20 percent of the herd occupied the monument's north end. The remainder was dispersed throughout vegetated areas, which covered 44 percent of the monument. No deer were observed making watering trips from the central or southern portions of the monument until mid-July. Analysis of forage moisture indicated that deer could have obtained sufficient water from plants until that time. After mid-July, drinking water would have been required for deer survival. Although Ritchie (1968) reported that deer did not appear to use waterholes, Griffith (1983) reported signs of springtime deer use at three waterholes: near The Sentinel, near Two-Point Butte, and at Ampitheater Cave.

Griffith (1983) found that deer could be predicted to migrate on the day after daytime temperatures exceeded 27°C and after nighttime low temperatures had exceeded 10°C for 12 days. This supported the suggestion that the mid-summer migration was a function of the deer's heat load and water requirements.

Individual deer generally showed fidelity to the same home ranges from year to year. Deer with home ranges in the central and southern areas in spring established new home ranges in the north end in July and then returned to their southern home ranges in mid- to late September (Griffith 1983).

From mid-July through September, 95 percent of the deer herd used the north end of the monument, causing soil disturbance in Douglas-fir and aspen stands used for bedding. No negative impact on forage was found during this time. In the fall, deer made 1-4 round trips between their southern and northern home ranges.

Winter Migration. Winter migration typically begins in early December. The studies of Ritchie (1968) and Griffith (1983) concluded that the monument's herd winters in two separate areas. One area is about 29-32 kilometers northeast of the monument in the foothills of the Pioneer Mountains near Moore, Idaho. The second is 70-100 kilometers south-southwest of the monument on the Snake River Plain, east of Jerome and north of Burley, Idaho.

Food Habits. Ritchie (1968) examined 11 rumen samples to determine the deer's food habits. Shrubs made up 87 percent of rumen contents, with bitterbrush (*Purshia tridentata*) accounting for 54 percent of the sample. Chokecherry (*Prunus virginiana*), serviceberry (*Amelanchier alnifolia*), aspen, and *Eriogonum* were also important forage items.

Twelve permanent 30-meter vegetation transects were established in areas of heavy deer use, as determined by hedged bitterbrush plants, deer trails and pellet groups, and observed feeding areas. Based on his findings, Ritchie (1968) suggested that the deer population may eventually need to be controlled to protect its summer range.

The subsequent analyses of Griffith (1983), however, disputed this opinion. Griffith did not find that the mule deer were damaging their forage supply. To monitor subsequent range conditions, Griffith (1984) developed standardized procedures for monitoring the Craters of the Moon National Monument deer herd and its habitat. These guidelines include methods for obtaining annual estimates of population size, productivity, and over-winter fawn survival. Permanent transects were established to monitor long-term vegetational trends over six-year cycles.

Pronghorn

Migratory movements of pronghorn wintering in the Little Lost River, Birch Creek, and Crooked Creek valleys north of INEL were studied from fall 1975 to summer 1977 (Hoskinson and Tester 1980). Summer ranges of radio-monitored pronghorn were located near the valleys' heads and averaged 2,033 hectares. Yearling home ranges were 2-5 times larger than those of adults. Winter home ranges averaged 2,300 hectares, but differed in size among valleys in 1975-1976. Winter ranges in the Little Lost River Valley were five times smaller than in Birch Creek Valley and 1.5 times smaller than in Crooked Creek Valley. This may be explained by differences in topography and extent of agricultural development among valleys. Some pronghorn moved among the three valleys during one or two successive winters.

The onset of spring migration coincided with decreased snow cover. Fall migration appeared to be related to moisture content of vegetation, but unrelated to weather. In summer, fall, and early winter, pronghorn were found in or migrating toward areas where forage plants had the highest moisture content (Hoskinson and Tester 1980).

Daily summer movements, activities, and home ranges of five pronghorn at INEL were studied in 1980. Home ranges were not used uniformly, rather, 17-29 percent of each home range was used 65-80 percent of the time. These "activity centers" were mostly used for resting/loafing and feeding. Feeding activity peaked in the morning and evening. Pronghorn moved an average 18.5 kilometers daily (Reynolds 1983).

Reynolds (1983) observed six incidents in which pronghorn chased or attacked coyotes. Three chases involved individual does defending their young. In two cases, herds of antelope chased a coyote. In the last case, a pronghorn and a short-eared owl jointly repelled a coyote.

Coyotes

Johnson and Hansen (1979b) compared coyote food habits in the central portion of INEL, where livestock grazing and coyote control were not allowed, with their food habits in the periphery of INEL, where grazing and control were allowed. They found that rabbits accounted for the greatest proportion of fragments in coyote scats throughout INEL. Both rabbits and coyotes were more abundant in the central, ungrazed portion of INEL. Rather than feeding opportunistically on livestock, coyotes appeared to concentrate in areas where their staple food was abundant.

The most important coyote foods were Nuttall's cottontails, montane voles, and northern pocket gophers. Coyote diets varied seasonally, with grass, insects, Ord's kangaroo rats, livestock, and yellow-bellied marmots important in winter diets. White-tailed jackrabbits, reptiles, and pronghorn were found in spring, summer, and fall diets, respectively. Although seasonal use of coyote foods suggests an opportunistic feeding strategy, 15 percent of available foods made up 80 percent of coyote diets. Coyotes at INEL showed a preference for relatively few mammal species as prey (MacCracken and Hansen 1982b).

Coyote home ranges at INEL were estimated using the ellipse method to be 46 square kilometers for females and 133 square kilometers for males, and using the modified minimum area method to be 29 square kilometers for females and 81 square kilometers for males. Coyotes traveled an average minimum distance of 27.6 kilometers per day. Peaks in summer "activity," based on distance moved, occurred just before sunrise and at sunset, while little activity occurred from 1100 to 1500 hours. Juveniles dispersed as far as 57 kilometers from their capture points (Woodruff and Keller 1982).

Home range use by coyotes at INEL was divided into three types of movement patterns believed to reflect resting behavior, hunting or investigative behavior, and ranging or traveling behavior. Home-range core areas were used mostly for resting and/or hunting (Laundre and Keller 1981).

Uncommon Species

Several large mammal species are transient residents of Craters of the Moon National Monument. Some of these may actually be fairly common, but due to their secretive habits, they are rarely seen. These include black bear, lynx, cougar, and red fox. There have been no studies of these animals in or adjacent to the monument. Some of the larger carnivore species formerly found within the monument, such as the wolf and grizzly bear, are now absent. The latter was last reported on the lava in 1915 (Blossom 1936).

Geographically Isolated Mammals

Three subspecies of mammals have been identified as being unique to the lava fields of Craters of the Moon National Monument and the vicinity. These include a subspecies of Great Basin pocket mouse, *Perognathus parvus idahoensis,* judged by Goldman (1922) to be restricted to lava flows of the Snake River Plain. The type location of this subspecies, the darkest form of the species, is Echo Crater.

One subspecies of yellow-pine chipmunk, *Eutamias amoenus craterieus,* also is believed to be endemic to the Snake River Plain, and was first recognized by Blossom (1937). The type specimen was taken from Grassy Cone.

Howell (1924) described a new race of pika from Echo Crater (*Ochotona princeps goldmani*) that has darker fur than any other pika.

GENERAL ECOLOGY

The equilibrium theory of island biogeography predicts that more isolated kipukas and smaller kipukas will support fewer plant and animal species. Carter-Lovejoy (1982) tested this theory using 14 kipukas in the Craters of the Moon lava field, east of Craters of the Moon National Monument. Individual kipukas covered 0.16-3.6 hectares and were isolated from "mainland" by 70-1,800 meters of lava. On each kipuka, small mammals and lizards were trapped and vegetation was sampled.

The number of plant species (25-49 per kipuka) and number of small mammal species (3-7 per kipuka) were significantly related to kipuka size. The relationship between kipuka size and number of plant species was believed to be related to the increased topographic diversity of larger kipukas. For small mammals, it was suggested that only the larger kipukas meet minimum area requirements for maintaining populations (Carter-Lovejoy 1982). The relationship between species numbers and kipuka size could not be explained by any single mechanism.

The numbers of plant and small mammal species were unrelated to the degree of kipuka isolation. Four of the small mammal species were captured on lava flows, suggesting that for some species, lava is not an isolating barrier (Carter-Lovejoy 1982).

A significant positive relationship was found between the number of animals captured per trap night and kipuka isolation. Carter-Lovejoy (1982) suggested that this may have been due to predation effects. Between times of predation by nonresident predators, small mammal populations may build up on more isolated kipukas, while on kipukas closer to mainland areas, small mammals may be subjected to more frequent predation, holding prey numbers lower. None of the kipukas was considered large enough to support resident coyotes or snakes.

ARCHAEOLOGY

Early explorers in the Craters of the Moon area reported finding Native American relics. They found trails across lava fields marked with rock piles and sagebrush branches (Stearns 1928a, Limbert 1924), rock structures thought to have been used to hold down the edges of tepees, rock piles that appeared to have been hunting blinds, arrowheads, and other artifacts (Stearns 1928a).

In 1966, an effort was made to locate and describe all archaeological sites within or near monument boundaries (Sneed 1966, 1967). The search was concentrated near water sources and areas supporting climax vegetation. Twenty-eight archaeological sites were located: 17 open sites (13 camping sites and four chipping stations) ranging in size from a few square meters to several thousand square meters, five cave sites, three quarry sites, and three rock structure sites including two hunting blind sites. In the two surveys, Sneed collected 285 stone artifacts, including 64 projectile points, and 71 pottery fragments from surface debris at the sites. The artifacts were similar to those found during excavation at Birch Creek Valley, suggesting that Craters of the Moon National Monument was occupied by Northern Shoshoni at some time from about 3,500 years ago to historic times (Sneed 1966,1967). The amount of uncovered cultural material indicated that aboriginal use of the monument had been minimal and for short periods, with the heaviest use at campsites in the northwest section where natural resources were most available.

VISITOR USE

The number of visitors to Craters of the Moon National Monument is estimated using an automatic traffic counter at the monument entrance. The annual number of visitors in 1973-1986 ranged from 162,454 in 1980 to 359,677 in 1978, with an average of 230,335 (Craters of the Moon National Monument 1973-1986). No consistent trend appeared over this time.

Holland (1979) studied visitor satisfaction at Craters of the Moon National Monument in relation to visitor expectations and activities. Visitors were given an expectancy questionnaire upon arriving at the visitor center and an accomplishment questionnaire just before leaving the monument. Eleven domains representing different dimensions of recreation preferences were used to measure visitor satisfaction. Seventy-seven people completed and returned both questionnaires. In addition, one-half of those surveyed were observed throughout their visits.

Expectations and accomplishments were highest for visitors in the domains "relationship with nature" and "learning-discovery," while "independence-autonomy," "reflecting on personal values," "achievement," and "meeting and observing new people" were less important expectations and less often accomplished. "Escaping physical pressure," "physical rest," "family togetherness," "escaping personal-social pressure," and "being with people" were moderately important expectations and were achieved moderately well (Holland 1979).

Although the monument's visitors accomplished less than they expected for all domains except "escaping personal-social pressure," they reported overall high satisfaction with their visits. Reported satisfaction was not shown to be related to the congruence of expectations and accomplishments. Satisfaction was also not found to be related to age, gender, type of group, frequency of park visitation, or number of visits to the monument (Holland 1979).

Satisfaction of individuals was, however, found to be related to satisfaction of other individuals in the same group. Satisfaction also was found to vary with activities pursued: photographers reported a significantly higher satisfaction level than non-photographers. Similar but less significant results appeared for visitors who had walked a nature trail or gone sightseeing at the smaller cones (Holland 1979).

Sixty-six percent of people surveyed were first-time visitors. Mean length of stay for day groups was 2 hours 33 minutes. For camping groups, mean length of stay was 18 hours. Campers made up 13 percent of the groups (Holland 1979).

Holland suggested that more interpretive contact might help visitors realize their expectations of learning and discovering nature, especially in light of the high percentage of first-time visitors. Because most visits were short, Holland recommended frequent, short interpretive walks. Holland (1979) also suggested that sequenced radio transmitters or audio cassette tapes be used for auto tours.

SUMMARY

Even a National Park Service unit as relatively small and isolated as Craters of the Moon National Monument has been the subject of a remarkable number of research studies. Table 3 gives a qualitative assessment of the natural and cultural history knowledge that has been gained from these studies.

Table 3. Qualitative assessment of natural and cultural history knowledge of Craters of the Moon National Monument.

Area of study	Degree of completeness (least complete.....most complete) 10 20 30 40 50 60 70 80 90 100
Geology	
General description	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Geologic history	xxxxxxxxxxxxxxxxxxxxxxxxxx
Substrate composition	xxxxxxxxxxxxxxxxxxxxxxx
Flora	
Description	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Species list	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Succession	
Volcanic areas	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Other areas	xxxxxxxxxxxxxx
Community ecology	xxxxxxxxxxxxxxxxxx
Fire history	xx
Fire effects	xxxx
Monitoring programs	x
Fauna	
Invertebrates	xxxx
Reptiles	xx
Birds	xx
Mammals	xxxxx
Monitoring programs	xxxx
Archaeology	xxxxxxxxxx
Visitor use	
Numbers	xxxxxxxxxxxxxxxxxxxxxx
Demography	xx
Air quality	
Monitoring programs	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Water quality	
Monitoring programs	xx
Soils	xxxx
Cultural history	xxxxxxxxxxxxxxxxxxxxxxxxxx
Legislative history	xxxxxxxxxxxxxxxxx
Climate	
Monitoring	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Information on the various resources at the monument is far from uniform. Geologic studies have been paramount, due, of course, to the extensive lava fields along the Great Rift. Consequently, the descriptions of the monument's geologic structure and our understanding of its geologic history are nearly complete.

Despite the predominance of lava fields, Craters of the Moon National Monument supports a surprising diversity of plant communities. Because of recent studies, these communities and the successional processes that helped create them are relatively well understood. The monument's fire history and the effects of fire on the monument's plant communities are, however, poorly known. To rectify this deficiency, in the summer of 1987 a fire ecology study began under the direction of the University of Idaho Cooperative Park Studies Unit (CPSU).

Relative to our knowledge of the monument's plants and geology, our knowledge of the monument's faunal communities also is poor. A project is now underway through the University of Idaho CPSU to survey the monument's bird and small- and medium-sized mammal communities and to develop a program to monitor changes in species composition and distribution. In addition, considerable ecological studies on several bird and mammal species found at the monument have been undertaken at the adjacent INEL. Thus, our ecological understanding of some species is greater than one might expect.

Air quality monitoring programs have received considerable attention at the monument, particularly since the 1984 finding that, in terms of particulate pollution, the monument has the cleanest air in the continental United States and is an EPA baseline reference point for visibility.

Like many parks, Craters of the Moon lacks a central repository or file system to manage its scientific data. Thus, finding and summarizing its research legacy was tedious. The anticipated continued growth in research at the monument means that the current methods of filing and documenting information and data need to be drastically revised. Otherwise, the difficulties in locating research in scattered and often unorganized files will multiply. Work began during the fall of 1987 to develop a microcomputer-based data management system for the monument that will parallel in structure that used by other national parks in the Northwest. The tabular compilations of research in this report (Appendix 1) will form the basis for that data base.

Throughout its history, Craters of the Moon National Monument has played an important role in the education of university students by serving as a field research site. Much of the research reviewed here has been accomplished through graduate research and incorporated into theses, 13 of which have been completed on monument resources. Almost 70 percent of this graduate work has been conducted through Idaho universities.

A great majority of the studies conducted at the monument have been subject-specific. There has been little attempt to synthesize and integrate past studies, or to conduct long-term studies emphasizing ecosystem processes. Yet, such studies are a necessary step if we are to broaden the effort to understand parks in terms of ecosystem processes and to solve the problems that threaten parks.

APPENDIX 1: TABULAR SUMMARY OF CRATERS OF THE MOON RESEARCH

Subject: General geology.

Date: 1901-1902.

Objectives: Determine the feasibility of obtaining ground water from wells in the Snake River Plain.

Methods: Reconnaissance.

Summary: In this first, detailed geological study of the Snake River Plain, major features including cinder cones, lava flows, and many types of volcanic ejecta are described. The Craters of the Moon area is referred to as "Cinder Buttes."

Suggestions: None.

References: Russell 1902, 1903.

Subject: General geology.

Date: 1921-1926.

Objectives: Explore and describe volcanic features.

Methods: Reconnaissance.

Summary: Individual geological features, including cinder cones, lava flows, volcanic ejecta, faults, caves, tree molds, and water sources are described in detail. First attempt to age lava flows by the paleomagnetic method. Three eruptive periods are recognized.

Suggestions: None.

References: Stearns 1924, 1928a, 1928b, 1930, 1931, 1963.

Subject: Lava Creek vents.

Date: 1929?

Objectives: Determine possibility of mining base-metal sulfides of lead and zinc from the Lava Creek District.

Methods: Reconnaissance and mapping.

Summary: Two lava vents (North Vent and South Vent), a small spatter cone, and an open fissure that are part of the Great Rift, 6-10 kilometers from the Snake River Plain in the Pioneer Mountains, are described in detail. Lava flowed 10 kilometers from South Vent onto the Snake River Plain.

Suggestions: None.

References: Anderson 1929a, 1929b.

Subject: Geology and water resources.

Date: 1928-1930.

Objectives: Determine source, movement, and disposal of ground water in the Snake River Plain.

Methods: Well sampling and water analysis.

Summary: Eighty-eight vents and 39 lava flows at the monument are distinguished. Three sets of fault scarps in the monument are noted. Wells near the monument showed that ground water was at least 304 meters deep. Persistent water in caves or other lava surfaces was found perched on bodies of ice.

Suggestions: None.

References: Stearns et al. 1938.

Subject: Grooved lava.

Date: 1938.

Objectives: Describe mechanism that formed grooved lava.

Methods: Field examination of Big Craters.

Summary: Grooves, striations, pock marks, and shark's tooth projections of thin lava flows at Big Craters were caused by pyroclastic material (blocks, bombs, lapilli) falling onto the surface of molten flows, indicating that during some periods, lava and pyroclastic material were extruded from the cone simultaneously.

Suggestions: None.

References: Nichols and Stearns 1940.

Subject: Big Craters.

Date: 1957.

Objectives: Prepare for designing an interpretive plaque.

Methods: Reconnaissance.

Summary: The sequence of events that created Big Craters is described.

Suggestions: None.

References: Zink 1957.

Subject: General geology and mapping.

Date: 1960.

Objectives: Determine relative ages of lava flows and prepare geologic map of the monument while avoiding duplication of previous work.

Methods: Reconnaissance, concentrated in northern part of monument. Stratigraphic relationships of flows were based on surface contacts, degree of weathering, cinder cover, and type of flow.

Summary: Lava flows and major volcanic features at the monument are mapped. Four eruptive periods are recognized. Types and formation of volcanic features are described.

Suggestions: Geologic mapping of the southern part of the monument, detailed petrographic studies of all specimens collected at the monument, mapping and description of lava tubes, further mapping in the Pioneer Mountains, petrographic analysis of xenoliths, and mapping of Devil's Orchard and Serrate flows and determination of their origin. Also suggests adding more of the Great Rift Zone to the monument.

References: Murtaugh 1961.

Subject: Geology of monument's northern end.

Date: 1978.

Objectives: Map the geology of the monument's north end and the surrounding area.

Methods: Field mapping. Microscopic petrographic analysis of thin sections.

Summary: Oldest rocks in the area are Mississippian Drummond Mine limestone (30 meters thick) and Scorpion formations (488 meters thick).

Suggestions: None.

References: Sidle 1979.

Subject: Lava tubes, tunnels, caves, and arches.

Date: 1959-1962.

Objectives: Describe lava tubes, tunnels, caves, arches, and the minerals found within.

Methods: Exploration and compass surveys.

Summary: Arco Tunnel, Natural Bridge, Amphitheater Cave, Crystal Pit, and Indian Tunnel are mapped and described. Coralloid opal was found in Arco tunnel. Gypsum, mirabilite, and jarosite were found in Crystal Pit and other caves.

Suggestions: Preserve Arco Tunnel for scientific study, but close it to the general public. Explore spatter cones in Vermillion Chasm.

References: Sanchez and Peck 1959; Sanchez 1960; Peck 1961, 1974b.

Subject: Cave mapping.

Date: 1984.

Objectives: Identify, map, and photograph caves, lava flows, and cave features in the monument.

Methods: Exploration and mapping.

Summary: Caves (53), cones, and natural bridges are classified according to hazards present, skills required to explore the caves, and archaeological, biological, and geological contents. Also noted are the number of cave entrances, lengths of passages, cave pattern and directional trend, vertical relief, presence of water, and type of protection needed and provided by the National Park Service.

Suggestions: None.

References: Jex 1984.

Subject: Idaho Rift System.

Date: Not stated.

Objectives: Not stated.

Methods: Low-level aerial reconnaissance, aerial photography, and radiocarbon dating.

Summary: The term "Idaho Rift System" is proposed to describe the Great Rift and the Open-Crack, King's Bowl, and Wapi rift sets. Based on radiocarbon dating, charred sagebrush from beneath the King's Bowl rift was approximately 2,130 years old.

Suggestions: None.

References: Prinz 1970.

Subject: Sub-surface temperature.

Date: Not stated.

Objectives: Test a method of long-term sub-surface temperature measurement.

Methods: Slow, temperature-sensitive, acid-catalyzed hydrolysis of sucrose solution to measure average subsurface temperatures. Thirty samples were buried along 40 kilometers of the Great Rift inside the monument; 150

samples were buried along 40 kilometers running south-southwest from the rift. All samples were left 1.3 meters underground for approximately 303 days.

Summary: Contrary to expectations, sub-surface temperatures increased with distance from the Great Rift. The authors speculated that this was caused by faults along the southern edge of the eastern Snake River Plain that increase local heat by heat transfer into percolating ground water or by simple dry conduction.

Suggestions: Test this method over known hot spots to establish the validity of the method.

References: Faler et al. 1971.

Subject: Mapping lava flows with LANDSAT data.

Date: Not stated.

Objectives: Not stated.

Methods: Digital processing of LANDSAT images, including classification and contrast stretching.

Summary: Radiance values of Craters of the Moon lava field pahoehoe flows showed a general correlation with flow age. Variations in radiance between flows were due to flow surface roughness, chemistry and mineralogy, and cover. Surface roughness allowed discrimination between aa and pahoehoe flows. Surface chemistry and mineralogy and surface cover allowed discrimination among pahoehoe flows of different ages.

Suggestions: Count sagebrush plants in low-altitude infrared photos of randomly selected pahoehoe flows to determine whether sagebrush is distributed in relation to local climate and/or age of lava flows.

References: Lefebvre 1975; Lefebvre and Abrams 1977a, 1977b.

Subject: Spectral response of lava.

Date: Not stated.

Objectives: Determine factors controlling spectral aging of lava flow surfaces.

Methods: Milton Multiband Radiometry (MMR) to determine the bidirectional reflectance factors (BRF) of pahoehoe flow surfaces from the ground. The MMR was equipped with filters to simulate LANDSAT MSS imagery. Sampled flows known from other studies to be about 2,000-12,000 years old.

Summary: BRF was greatly increased by lichen cover on the lava flows. Chemical weathering of the flow surface also increased BRF. On flows older than about 8,000 years, lichens and weathering caused little further change in BRF, and cover by vascular plants and sediment contributed most to increases in BRF.

Suggestions: None.

References: Rothery and Lefebvre 1985.

Subject: Radar observations of lava.

Date: 1981.

Objectives: Examine utility of radar for detecting fissure vent areas through characterization of lava flow surface texture.

Methods: Examination of X band and L band synthetic aperture, side-looking, airborne radar images for surface texture characteristics. Geologic maps, aerial photos, and field observations were used to evaluate the interpretation of radar images.

Summary: Differences in lava surface textures were displayed best in the L band, cross-polarized images, but spatter ramparts were apparent only in the X band images. Success of this method was based on the assumption that lava flows progress from smooth pahoehoe at fissure vents, through rougher pahoehoe, and then to aa away from vents, but this was not always the case. Spatter ramparts were better indicators of fissure vent locations.

Suggestions: Conduct more detailed field studies on the surface roughness of lava flows and the radar signatures of lava textures.

References: Viglienzone and Greeley 1981, Martel 1984, Martel and Greeley 1984.

Subject: Radiocarbon ages of lava flows.

Date: 1969-1970.

Objectives: Determine extent, volume, and age of material erupted from the Great Rift. Contribute to understanding of the monument's fissure-type eruptions.

Methods: Mapping of lava flows using aerial photos. Radiocarbon dating of sagebrush rootlets dug from under lava flows. Collection of xenoliths from the Serrate Flow and the floor of North Crater.

Summary: Radiocarbon ages of sagebrush, believed to represent flow ages late in volcanic history of the area, were 2,080 $\pm$ 85 years BP for sagebrush dug from under pahoehoe flows, 2,130-2,310 $\pm$ 80 years BP for sagebrush from tree molds at Trench Mortar Flat, and 2,140 $\pm$ 60 years BP for sagebrush from a tree mold near the northwest base of The Watchman. Xenoliths consisted of gneissic material. Two previously unreported types of xenoliths, composed of pink rhyolite and a brown, pumice-like material, were discovered.

Suggestions: Continue mapping individual lava flows and devote further study to (1) the eruptive sequence along the Great Rift, (2) the Blue Dragon flow and other flows with blue surfaces (unique to the monument), (3) lava tube development, (4) the intermixture of aa and pahoehoe flows, and, (5) xenoliths, to compare them with outcrops of basement rock in adjacent areas.

References: Bullard and Rylander 1970; Bullard 1971a, 1971b, 1976; Valastro et al. 1972.

Subject: Paleomagnetism.

Date: Not stated.

Objectives: Not stated.

Methods: Paleomagnetic measurement of lava flows.

Summary: Paleomagnetic measurements indicated at least six short eruptive episodes occurred in the Craters of the Moon lava field, beginning about 11,000 years BP.

Suggestions: None.

References: Champion and Shoemaker 1977.

Subject: Evolution of the Craters of the Moon lava field.

Date: 1970s-1986.

Objectives: Determine eruptive history, eruptive mechanisms, and magma petrogenesis of the Great Rift.

Methods: Lava flow mapping, radiocarbon dating, paleomagnetic measurements, petrographic and chemical analysis, and X-ray fluorescence spectroscopy.

Summary: Eight eruptive periods at Craters of the Moon lava field, beginning about 15,000 years ago and ending about 2,000 years ago, with an average interval between eruptive periods of about 2,000 years are recognized. Individual flows are placed into periods based on age relationships determined by a variety of methods. Magma output for the Craters of the Moon lava field was estimated to be about 1.5 km^3/1,000 years between 15,000 and 7,000 years BP and 2.8 km^3/1,000 years from 7,000 to 2,000 years BP. Chemical composition of rocks is presented.

Suggestions: Radiocarbon methods can be used to date other lava fields. Dates of other Craters of the Moon lava flows may be obtained by radiocarbon methods or by other methods such as thermoluminescence dating of flows or of sediments beneath flows.

References: Kuntz 1985; Kuntz et al. 1982, 1983, 1985, 1986a, 1986b.

Subject: Chemical composition of lava and volcanic rocks.

Date: Not stated.

Objectives: Determine origin of lavas from the Craters of the Moon lava field and their relation to Snake River Plain volcanism.

Methods: Chemical analysis of lava and mass spectrophotometric determination of strontium isotope ratios in volcanic rocks from the monument.

Summary: Craters of the Moon lavas had high strontium isotope ratios and appeared to be derived from Snake River Plain olivine tholeiite magma by the combined processes of fractional crystallization and crustal contamination. The lavas ranged from the alkali- and phosphorus-rich ferrobasalts of pahoehoe and aa flows to the ferrolatites of blocky flows. Chemical analyses of lavas and xenoliths are presented.

Suggestions: None.

References: Leeman and Manton 1971; Leeman et al. 1975, 1976, 1978; Leeman 1979; Matty et al. 1982.

Subject: Chemical composition of lava and volcanic rocks.

Date: Not stated.

Objectives: Not stated.

Methods: Rapid rock analysis of nine lava samples and evaluation of previously unpublished chemical analyses of Craters of the Moon lavas.

Summary: Chemical compositions of lava, xenocrysts, and xenoliths are presented. Several flows were characterized by high strontium isotope ratios and low radiogenic lead content. The lavas were estimated to have been liquid at 1,110-1,060°C.

Suggestions: None.

References: Stone 1969, Stone et al. 1970.

Subject: Blue Dragon basalt.

Date: Not stated.

Objectives: Explain the appearance of Blue Dragon basalt.

Methods: Microscopic examination and electron microprobe analysis of thin sections of lava and microscopic spectrophotometry.

Summary: Color of Blue Dragon lava is caused by electron transfer from Fe^{2+} to Fe^{3+}. Fe^{2+} content was high, probably due to the presence in the magma while it was confined just prior to eruption of 2-3 percent phosphorus as a reducing agent. A thin siliceous film on the lava surface transmits and scatters the blue light.

Suggestions: None.

References: Miller 1969, 1970; Faye and Miller 1973.

Subject: Secondary minerals.

Date: Not stated.

Objectives: Not stated.

Methods: Identification by X-ray diffraction and differential thermal analysis of minerals collected from the major Holocene lava fields of the Snake River Plain.

Summary: Mirabilite, jarosite, gypsum, and thenardite from the monument were identified. It was hypothesized that mineral deposits in lava caves were fumarolic in origin, but that the more soluble minerals went through solution, leaching, transport, and redeposition by ground water.

Suggestions: None.

References: Karlo et al. 1980.

Subject: Primary plant succession.

Date: Summers, 1936-1938.

Objectives: Not stated.

Methods: Measurement of temperature and evaporation below and at lava flow and cinder cone surfaces and of soil moisture on cinder cones. Characterization of plant succession using study plots on pahoehoe flows of different ages.

Summary: Occurrence of various plant species is explained based on soil accumulation and available water on lava flows and cinder cones. Soil on lava flows accumulates first in crevices, then in joints, and finally deposits in an even layer over the flow surface. During this process, plants are eliminated from crevices and joints and eventually are replaced by a grass-sage climax community. Cinder cones supported a pioneer herb community, a tree-dominated community, and a shrub-dominated community.

Suggestions: None.

References: Eggler 1941.

Subject: Plant succession and community types.

Date: Summers, 1983-1984.

Objectives: Understand and describe the sequence of vegetation and soils through the stages of primary succession on east-facing, 2,200- to 12,600-year-old cinder cone slopes. Develop baseline information on vegetation; describe and map vegetation types.

Methods: Measurement of foliar cover of all plant species and of soil moisture, texture, total nitrogen, available phosphorus, and total sulfate below individuals of each major plant species and at bare areas. Measurement of seed densities within the canopies of *Eriogonum ovalifolium* and at bare areas. Ground truthing of vegetation types.

Summary: Because of buried past A horizons at most sites, a chronosequence of vegetation and soils could not be developed. *E. ovalifolium* and *Phacelia hastata* were initial colonizers of cinder cones and were negatively associated with their own canopy regions and with two later-successional species, *E. umbellatum* and *Pinus flexilis.* Twenty-six vegetation types were identified and mapped.

Suggestions: None.

References: Day 1985, Day and Wright 1985.

Subject: Secondary plant succession.

Date: 1966-1967.

Objectives: Establish plots for a long-term analysis of secondary plant succession on a roadbed.

Methods: Compilation of a checklist of plants growing on a roadbed and on the adjacent plain. Determination of the abundance and cover class of each plant species within 10 1-square-meter quadrats along the road closure. Photography of quadrats.

Summary: The first two years of what was intended to be a long-term monitoring program are discussed.

Suggestions: Analyze vegetational changes within permanent experimental and control quadrats until climax community vegetation is established. Photograph at annual intervals. Determine effects of abiotic factors. Complete soil analyses.

References: Urban 1967a, 1967b.

Subject: Soils and plants of the Carey Kipuka.

Date: 1958-1963.

Objectives: Describe plants that grow on different soils in an area undisturbed by grazing.

Methods: Not stated.

Summary: Six soils belonging to the Chestnut great soil group are identified and soil horizons and associated plant communities are described. Total herbage production and species composition varied between years and between soil taxonomic units in the same year. Herbage production was closely correlated with precipitation from October to March, available soil moisture at the end of March, evapotranspiration, and total water used in herbage production.

Suggestions: None.

References: Hugie et al. 1964, Passey et al. 1964.

Subject: Vegetation of the Carey Kipuka.

Date: 1955-1963.

Objectives: Not stated.

Methods: Sampling of vegetation and soils at eight permanently marked stands.

Summary: Three community types are recognized: (1) *Artemisia tripartita/Festuca idahoensis,* (2) *Artemisia tridentata/Festuca idahoensis/Agropyron spicatum,* and (3) *Artemisia longiloba/Festuca idahoensis/Stipa thurberiana.*

Suggestions: None.

References: Tisdale et al. 1965.

Subject: Dwarf mistletoe.

Date: 1966-1967.

Objectives: Determine the age distribution of mistletoe infection at the monument. Determine effects of mistletoe on annual growth of limber pine. Compare infection levels in stands before and after control measures. Assess changes in plant communities resulting from control efforts.

Methods: Reconnaissance of dwarf mistletoe along 28 transects in limber pine stands.

Summary: Infection was found to be nearly as widespread as the limber pine. Infection apparently spread from west to east. Initial infection occurred at least 209 years previously. Tree height was positively correlated with infection intensity, stand density was not. After the eradication program, the percentage of heavily infected trees decreased, but the percentage of lightly and moderately infected trees increased. Dispersal agents were not determined, but the seed ejection mechanism of dwarf mistletoe, unidirectional winds, and animals were suspected to be important. Where shrub understories were closed at the time of tree removal, plant succession was accelerated and no regeneration was found. Regeneration was occurring on sites that had been in pioneer stages of succession prior to tree removal.

Suggestions: Conduct basic research to determine ages of lava flows, species imprinted in tree molds and lava trees, mortality rates of limber pine seedlings under controlled and natural conditions, rates of plant succession, and dispersal agents of dwarf mistletoe.

References: Urban 1968a.

Subject: Checklist of vascular plants.

Date: 1967.

Objectives: Create a comprehensive collection and key to the monument's plants.

Methods: Not stated.

Summary: A dichotomous key to 291 species of vascular plants is presented. Seven general vegetation types are described.

Suggestions: None.

References: Wunner 1967.

Subject: Checklist of vascular plants.

Date: 1968.

Objectives: Update the work of Wunner (1967).

Methods: Not stated.

Summary: Common and scientific names for 304 plants collected or reported within the monument are listed. A brief introduction describes plant succession.

Suggestions: None, but indicates plants missing from the monument's herbarium.

References: Urban 1968b, 1971.

Subject: Insects.

Date: 1964-1965, 1967.

Objectives: Inventory the monument's insects.

Methods: A variety of standard collection methods at 12 collecting stations within the monument.

Summary: Found 20 orders, 248 families, 1,144 genera, and 2,064 species and subspecies. More than 30 species were new to science. Numbers of insect species at a station were related to the type and age of geological substrate and to the variety and abundance of plants at a site. The three most abundant orders were Hymenoptera (705 spp.), Diptera (521 spp.), and Coleoptera (324 spp.).

Suggestions: None.

References: Horning 1966, Horning and Barr 1970.

Subject: Cave invertebrates.

Date: 1961-1969.

Objectives: Summarize invertebrate fauna of volcanic caves of North America.

Methods: Not stated.

Summary: Six families and five genera found in the monument's caves and lava tubes are mentioned.

Suggestions: None.

References: Peck 1973.

Subject: Idaho lava tube beetle.

Date: 1965.

Objectives: Not stated.

Methods: Not stated.

Summary: A new subfamily and species of beetle, *Glacicavicola bathyscioides,* known only from ice caves in Idaho, including Boy Scout Cave at the monument, is described.

Suggestions: None.

References: Westcott 1968.

Subject: Idaho lava tube beetle.

Date: 1969-1971.

Objectives: Not stated.

Methods: Laboratory observation of 52 live beetles captured from the monument.

Summary: The beetles apparently scavenged arthropod remains. They lived at least two years in the laboratory.

Suggestions: None.

References: Peck 1974a.

Subject: Great Basin wildrye and associated insect fauna, emphasizing the wheat stem sawfly.

Date: 1982-1983.

Objectives: Identify the relationships between Great Basin wildrye and its associated insect fauna; describe the life history of the wheat stem sawfly on wildrye and determine its impacts on seed production.

Methods: Determination of life stage, abundance, and plant part used for each insect species collected. Monitoring of sawfly development and estimation of its density in wildrye. Collection and weighing of wildrye seeds and comparison of culm diameters and germination rates from infested and uninfested wildrye tillers.

Summary: Forty-five insect species were found on Great Basin wildrye at the monument; the majority were oligophagous. Five parasitoid species were reared from insect hosts. Sixty-two to 73 percent of wildrye plants and 22 percent of tillers were infested with sawflies. Phenology of the sawfly and wildrye was three weeks later at the monument than at INEL. Adult sawflies emerged from wildrye culms concurrent with inflorescences emerging from grass sheaths. Eggs were deposited in larger stems. Seed weight and number of seeds per floret were significantly lower in culms containing sawfly larvae. Germination rates from sawfly-infested and noninfested culms were the same.

Suggestions: None.

References: Youtie 1986.

Subject: Birds.

Date: 1967-1970.

Objectives: Not stated.

Methods: Field observation supplemented with study of records on file at the monument.

Summary: Avian species (141) at the monument are listed: 72 migrants, 43 summer residents, 18 permanent residents, and eight winter residents (Appendix 2).

Suggestions: None.

References: Carter 1970.

Subject: Birds and mammals.

Date: 1955-1957.

Objectives: Not stated.

Methods: Field observation.

Summary: Nineteen mammalian species (Appendix 3) and five avian species at the monument are listed.

Suggestions: None.

References: Newman 1958.

Subject: Mammals.

Date: 1937.

Objectives: Conduct an ecological survey of the monument's mammals.

Methods: Field identification and use of reports by residents.

Summary: Thirty-three mammalian species are listed (Appendix 3). A previously undescribed race of chipmunk, *Eutamias amoenus craterieus,* was discovered; type location is Grassy Cone.

Suggestions: None.

References: Blossom 1936, 1937.

Subject: Mammals.

Date: 1967-1968.

Objectives: Study mammalian habitats and faunal relationships.

Methods: Study of 18 habitats, trapping during 2,222 total trap nights.

Summary: Forty-five species at the monument are listed (Appendix 3); two species were recorded at the monument for the first time, the vagrant shrew and western harvest mouse.

Suggestions: Study the subspecies of *Thomomys talpoides*, status of *Mustela erminea*, natural history and taxonomy of bats, taxonomy of *Eutamias*, predator-prey relationships, mammalian parasites, and whether altitudinal differences exist for *Microtus montanus* and *M. longicaudus*.

References: Fuller 1969.

Subject: Bats.

Date: December 1984-January 1985.

Objectives: Survey potential bat hibernacula.

Methods: Surveying of bats at lava tube caves at INEL and at the monument's Arco Tunnel. Determination of temperature and humidity in caves.

Summary: The small-footed myotis and Townsend's big-eared bat were found at INEL; only the small-footed myotis was found in Arco Tunnel. Townsend's big-eared bats preferred significantly warmer areas than the small-footed myotis, but occurred throughout the caves. The small-footed myotis hung in tiny pockets or crevices. The little brown myotis and big brown bat were also believed to hibernate in southeastern Idaho.

Suggestions: Complete more extensive surveys of caves, including a wider variety of cave types.

References: Genter 1986.

Subject: Pocket mouse.

Date: 1921.

Objectives: Not stated.

Methods: Not stated.

Summary: A new subspecies of pocket mouse was discovered, *Perognathus parvus idahoensis;* type location is the monument's Echo Crater. It is the darkest form of the species; its color apparently is associated with its lava environment.

Suggestions: None.

References: Goldman 1922.

Subject: Mule deer.

Date: 13-16 June, 1955.

Objectives: Not stated.

Methods: Field observation.

Summary: It was thought that deer foraged primarily on sagebrush and buck-brush and migrated south through the monument in winter.

Suggestions: Survey wildlife and use the information to prepare a booklet for the public. Prepare a booklet about plants for the public. Survey water sites.

References: Newman 1955.

Subject: Mule deer.

Date: April 1967-January 1968.

Objectives: Determine mule deer herd population size, movement patterns, and condition. Assess range conditions within the monument.

Methods: Capture and marking with ear tags and neck bands of 33 deer, fitting of six with radio transmitters. (Marked deer were relocated 386 times.) Determination of deer movements from field observations and track counts. Establishment of permanent transects for assessing range trends.

Summary: Estimated 1967 population size to be 335 with 48 percent fawns. Herd divided into two groups in summer. The group in the monument's north end was sedentary; the southern group migrated 6.4-12.8 kilometers during the driest period. Bitterbrush was the staple forage species. The herd wintered 32 kilometers northeast of monument headquarters.

Suggestions: The deer population may eventually need to be controlled to protect the range. Run vegetation transects at three- to five-year intervals. Conduct yearly herd trend counts.

References: Ritchie 1968.

Subject: Mule deer.

Date: 1980-1982.

Objectives: Describe area use patterns of deer. Estimate population size. Study production, mortality, and recruitment.

Methods: Marking and release of 100 deer and equipping of 20 with radio transmitters. (Marked deer were relocated 2,381 times.) Moisture content analysis of vegetation samples. Determination of food habits from fecal pellet analysis.

Summary: Deer occupied the monument from April through November and wintered in two separate areas: 35 kilometers to the northeast, near Moore, Idaho and 70-100 kilometers south-southwest on the Snake River Plain, east of Jerome and north of Burley, Idaho. Midsummer migration was apparently a function of the deer's heat load and water requirements. The deer population did not appear to be rapidly increasing or damaging its forage supply at the monument. Fall population sizes were estimated as 478, 515, and 351 for 1980, 1981, and 1982. Average sex/age composition was 40 percent fawns, 41 percent does, 8 percent yearling males, and 11 percent adult males. Hunters killed 15.1 percent of the herd annually. Standard operating procedures for monitoring herd and vegetation were developed.

Suggestions: Monitor spring and fall deer population characteristics yearly. Document road-killed and hunter-killed deer. Pay rewards for tags returned from monument deer. Maintain law-enforcement program. Begin a prescribed burning program to prevent a large-scale fire. Reduce road kills with reflectors and signs or by phasing out lawns at the monument's headquarters.

References: Griffith 1983, 1984.

Subject: Plants and animals on kipukas and adjacent lava flows.

Date: 1979.

Objectives: Survey flora and fauna of lava environment. Study plant community composition and distribution in relation to soils and topography. Test the equilibrium theory of island biogeography. Determine relationships between plant and animal distributions and kipuka size and degree of isolation.

Methods: Vegetation and soil sampling. Trapping of small mammals and lizards on 14 kipukas in the Craters of the Moon lava field, east of the monument.

Summary: Thirteen mammals (Appendix 3) and five reptiles were captured and/or observed. The numbers of plant species (maximum 49) and animal species (maximum 7) on a kipuka were significantly related to kipuka size, but not to the degree of kipuka isolation. Mammal density was positively related to kipuka isolation.

Suggestions: Study the relationship between mammal density and kipuka isolation, especially with respect to predation effects.

References: Anderson and Lovejoy 1979, Carter-Lovejoy 1982.

Subject: Visitor satisfaction.

Date: Summer 1978.

Objectives: Determine specific expectations and activities that contribute to visitor satisfaction in a park. Document visitor behavior in a park. Further the understanding of leisure satisfaction.

Methods: Questionnaire administration and observation of visitor activity.

Summary: Visitor expectations and accomplishments were highest in the areas "relationship with nature" and "learning-discovery." Overall, visitors were very satisfied, but accomplishment was less than expected for 10 of 11 recreation preference categories.

Suggestions: Improve realization of expectations with more interpretive programs.

References: Holland 1979.

Subject: Archaeology.

Date: June 1966.

Objectives: Locate and describe all archaeological sites within or near monument boundaries.

Methods: Searching on foot and by airplane, concentrated near water sources and areas with climax vegetation.

Summary: Twenty-eight sites were located: 17 open sites (camping sites and chipping stations), five cave sites, three rock structure sites, two hunting blind sites, and three quarry sites. Most sites represented short periods of occupation. Collected 285 stone artifacts and 71 pottery fragments. Artifacts and their geographical location suggested occupation by Northern Shoshoni.

Suggestions: Excavate eight sites in north and central areas of monument.

References: Sneed 1966, 1967.

APPENDIX 2: BIRDS OF CRATERS OF THE MOON NATIONAL MONUMENT

Table 2-1. Birds of Craters of the Moon National Monument. After Carter (1970) and Anon. (1982).

Family / Common name	Scientific name
Podicipedidae	
Eared grebe	*Podiceps nigricollis*
Ardeidae	
Great blue heron	*Ardea herodias*
Anatidae	
Tundra swan	*Cygnus columbianus*
Canada goose	*Branta canadensis*
Mallard	*Anas platyrhynchos*
Snow goose	*Chen caerulescens*
Green-winged teal	*Anas crecca*
Blue-winged teal	*Anas discors*
Cathartidae	
Turkey vulture	*Cathartes aura*
Accipitridae	
Bald eagle	*Haliaeetus leucocephalus*
Northern harrier	*Circus cyaneus*
Sharp-shinned hawk	*Accipiter striatus*
Cooper's hawk	*Accipiter cooperii*
Northern goshawk	*Accipiter gentilis*
Swainson's hawk	*Buteo swainsoni*
Red-tailed hawk	*Buteo jamaicensis*
Ferruginous hawk	*Buteo regalis*
Rough-legged hawk	*Buteo lagopus*
Golden eagle	*Aquila chrysaetos*
Falconidae	
American kestrel	*Falco sparverius*
Merlin	*Falco columbarius*
Prairie falcon	*Falco mexicanus*
Phasianidae	
Gray partridge	*Perdix perdix*
Chukar	*Alectoris chukar*
Ring-necked pheasant	*Phasianus colchicus*
Blue grouse	*Dendragapus obscurus*
Ruffed grouse	*Bonasa umbellus*
Sage grouse	*Centrocercus urophasianus*
Charadriidae	
Killdeer	*Charadrius vociferus*
Scolopacidae	
Spotted sandpiper	*Actitis macularia*
Common snipe	*Gallinago gallinago*
Laridae	
Ring-billed gull	*Larus delawarensis*
Herring gull	*Larus argentatus*
Columbidae	
Rock dove	*Columba livia*
Mourning dove	*Zenaida macroura*
Strigidae	
Western screech owl	*Otus kennicotti*
Great horned owl	*Bubo virginianus*
Long-eared owl	*Asio otus*
Short-eared owl	*Asio flammeus*
Northern saw-whet owl	*Aegolius acadicus*
Caprimulgidae	
Common nighthawk	*Chordeiles minor*
Common poorwill	*Phalaenoptilus nuttallii*
Trochilidae	
Calliope hummingbird	*Stellula calliope*
Rufous hummingbird	*Selasphorus rufus*
Alcedinidae	
Belted kingfisher	*Ceryle alcyon*
Picidae	
Lewis' woodpecker	*Melanerpes lewis*
Red-headed woodpecker	*Melanerpes erythrocephalus*
Yellow-bellied sapsucker	*Sphyrapicus varius*
Williamson's sapsucker	*Sphyrapicus thyroideus*
Downy woodpecker	*Picoides pubescens*
Hairy woodpecker	*Picoides villosus*
Northern flicker	*Colaptes auratus*
Tyrannidae	
Olive-sided flycatcher	*Contopus borealis*
Western wood-pewee	*Contopus sordidulus*
Dusky flycatcher	*Empidonax oberholseri*
Western flycatcher	*Empidonax difficilis*
Say's phoebe	*Sayornis saya*
Western kingbird	*Tyrannus verticalis*
Eastern kingbird	*Tyrannus tyrannus*
Alaudidae	
Horned lark	*Eremophila alpestris*
Hirundinidae	
Violet-green swallow	*Tachycineta thalassina*
Cliff swallow	*Hirundo pyrrhonota*
Barn swallow	*Hirundo rustica*
Corvidae	
Gray jay	*Perisoreus canadensis*
Steller's jay	*Cyanocitta stelleri*
Pinyon jay	*Gymnorhinus cyanocephalus*
Clark's nutcracker	*Nucifraga columbiana*
Black-billed magpie	*Pica pica*
American crow	*Corvus brachyrhynchos*
Common raven	*Corvus corax*
Paridae	
Black-capped chickadee	*Parus atricapillus*
Mountain chickadee	*Parus gambeli*
Sittidae	
Red-breasted nuthatch	*Sitta canadensis*
White-breasted nuthatch	*Sitta carolinensis*
Certhiidae	
Brown creeper	*Certhia americana*
Troglodytidae	
Rock wren	*Salpinctes obsoletus*
House wren	*Troglodytes aedon*
Winter wren	*Troglodytes troglodytes*
Cinclidae	
American dipper	*Cinclus mexicanus*
Muscicapidae	
Golden-crowned kinglet	*Regulus satrapa*
Ruby-crowned kinglet	*Regulus calendula*
Western bluebird	*Sialia mexicana*
Mountain bluebird	*Sialia currucoides*
Townsend's solitaire	*Myadestes townsendi*
Swainson's thrush	*Catharus ustulatus*
Hermit thrush	*Catharus guttatus*

Table 2-1. (Con't)

Family Common name	Scientific name
American robin	*Turdus migratorius*
Varied thrush	*Ixoreus naevius*
Mimidae	
Gray catbird	*Dumetella carolinensis*
Sage thrasher	*Oreoscoptes montanus*
Brown thrasher	*Toxostoma rufum*
Motacillidae	
Water pipit	*Anthus spinoletta*
Bombycillidae	
Bohemian waxwing	*Bombycilla garrulus*
Cedar waxwing	*Bombycilla cedrorum*
Laniidae	
Northern shrike	*Lanius excubitor*
Loggerhead shrike	*Lanius ludovicianus*
Sturnidae	
European starling	*Sturnus vulgaris*
Vireonidae	
Solitary vireo	*Vireo solitarius*
Warbling vireo	*Vireo gilvus*
Emberizidae	
Orange-crowned warbler	*Vermivora celata*
Nashville warbler	*Vermivora ruficapilla*
Yellow warbler	*Dendroica petechia*
Yellow-rumped warbler	*Dendroica coronata*
Townsend's warbler	*Dendroica townsendi*
American redstart	*Setophaga ruticilla*
MacGillivray's warbler	*Oporornis tolmiei*
Wilson's warbler	*Wilsonia pusilla*
Yellow-breasted chat	*Icteria virens*
Western tanager	*Piranga ludoviciana*
Black-headed grosbeak	*Pheucticus melanocephalus*
Lazuli bunting	*Passerina amoena*
Green-tailed towhee	*Pipilo chlorurus*
Rufous-sided towhee	*Pipilo erythropthalmus*
Chipping sparrow	*Spizella passerina*
Brewer's sparrow	*Spizella breweri*
Vesper sparrow	*Pooecetes gramineus*
Lark sparrow	*Chondestes grammacus*
Black-throated sparrow	*Amphispiza bilineata*
Sage sparrow	*Amphispiza belli*
Savannah sparrow	*Passerculus sandwichensis*
Fox sparrow	*Passerella iliaca*
Song sparrow	*Melospiza melodia*
Lincoln's sparrow	*Melospiza lincolnii*
White-crowned sparrow	*Zonotrichia leucophrys*
Dark-eyed junco	*Junco hyemalis*
Snow bunting	*Plectrophenax nivalis*
Red-winged blackbird	*Agelaius phoeniceus*
Western meadowlark	*Sturnella neglecta*
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*
Brewer's blackbird	*Euphagus cyanocephalus*
Brown-headed cowbird	*Molothrus ater*
Northern oriole	*Icterus galbula*
Fringillidae	
Rosy finch	*Leucosticte arctoa*
Pine grosbeak	*Pinicola enucleator*
Cassin's finch	*Carpodacus cassinii*
House finch	*Carpodacus mexicanus*
Red crossbill	*Loxia curvirostra*
Common redpoll	*Carduelis flammea*
Pine siskin	*Carduelis pinus*
American goldfinch	*Carduelis tristis*
Evening grosbeak	*Coccothraustes vespertinus*
Passeridae	
House sparrow	*Passer domesticus*

APPENDIX 3: MAMMALS OF CRATERS OF THE MOON NATIONAL MONUMENT

Table 3-1. Mammals of Craters of the Moon National Monument.

	Status[1]				
	Study[2]				
Common name **Scientific name**	**1936**	**1958**	**1969**	**1979**	**1982**
Vagrant shrew *Sorex vagrans*			C	C	L
Little brown myotis *Myotis lucifugus*					L
Long-eared myotis *Myotis evotis*			X		L
Small-footed myotis[3] *Myotis leibii*					
Big brown bat *Eptesicus fuscus*					L
Hoary bat *Lasiurus cinereus*					L
Townsend's big-eared bat *Plecotus townsendii*	R	L	X		L
Pika *Ochotona princeps*	L	L	R	O	L
Pygmy rabbit *Brachylagus idahoensis*	L		OX		L
Nuttall's cottontail *Sylvilagus nuttalli*	L	L	O	CO	L
Snowshoe hare *Lepus americanus*	L	L	R		L
White-tailed jackrabbit *Lepus townsendii*	L	L	RX		L
Black-tailed jackrabbit *Lepus californicus*	L	L	O	O	L
Least chipmunk *Eutamias minimus*	L	L	RX	CO	L
Yellow-pine chipmunk *Eutamias amoenus*		L	CO		L
Yellow-bellied marmot *Marmota flaviventris*	R	L	CO	O	L
Townsend's ground squirrel *Spermophilus townsendii*			H	CO	
Columbian ground squirrel *Spermophilus columbianus*	R	L	CO		
Golden-mantled ground squirrel *Spermophilus lateralis*	L	L	CO		L
Red squirrel *Tamiasciurus hudsonicus*	L	L	CO		L
Northern pocket gopher *Thomomys talpoides*	L	L	CO		L
Great Basin pocket mouse *Perognathus parvus*	L		C	C	L
Ord's kangaroo rat *Dipodomys ordii*	C[4]		C		
Beaver *Castor canadensis*		L	R		L
Western harvest mouse *Reithrodontomys megalotis*			C	C	L
Deer mouse *Peromyscus maniculatus*	L		C	C	L
Northern grasshopper mouse *Onychomys leucogaster*	L[4]				
Bushy-tailed woodrat *Neotoma cinerea*	C	L	CO	C	L
Montane vole *Microtus montanus*	L		C	C	L
Long-tailed vole *Microtus longicaudus*			C		L
Muskrat *Ondatra zibethicus*			R		
Western jumping mouse *Zapus princeps*			C		L
Porcupine *Erethizon dorsatum*	L	L	RS		L
Coyote *Canis latrans*	O		RS		L
Red fox *Vulpes vulpes*	R		R		L
Kit fox *Vulpes macrotis*					L
Black bear *Ursus americanus*	R		R		L
Grizzly bear *Ursus horribilis*	R		R		
Raccoon *Procyon lotor*			R		L
Ermine *Mustela erminea*	C?[5]		CR		L
Long-tailed weasel *Mustela frenata*	C?[5]		R		L
Badger *Taxidea taxus*	R		R		L

[1] C = collected, captured, trapped, or road-killed, this study; H = hypothetical; L = listed, this study; O = observed, this study; R = reported previously; S = sign: scat, tracks, or remains; X = collected, captured, trapped, or road-killed previously.
[2] 1936 = Blossom; 1958 = Newman; 1969 = Fuller; 1979 = Anderson and Lovejoy; 1982 = Anon.
[3] Genter 1986.
[4] Outside Craters of the Moon National Monument boundaries but within the Craters of the Moon lava field.
[5] It was not determined whether this was *Mustela erminea* or *M. frenata*.

Table 3-1. (Con't)

Common name Scientific name	Status[1] Study[2] 1936	1958	1969	1979	1982
Western spotted skunk *Spilogale gracilis*	R		R		L
Striped skunk *Mephitis mephitis*	R		R		L
Mountain lion *Felis concolor*			R		L
Lynx *Felis lynx*	R				
Bobcat *Felis rufus*		L	R		L
Elk *Cervus elaphus*	R		R		L
Mule deer *Odocoileus hemionus*	L	L	OX	O	L
Pronghorn *Antilocapra americana*	R	L	R		L
Bison *Bison bison*			R		
Bighorn sheep *Ovis canadensis*	R		R		

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