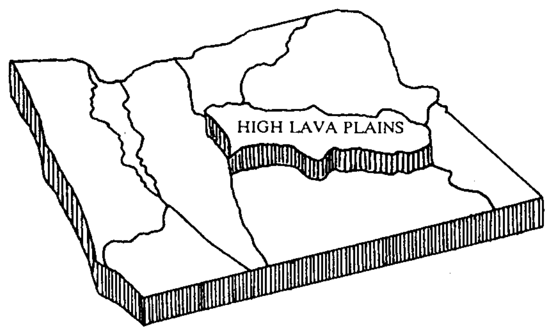
High Lava Plains

Physiography

The High Lava Plains physiographic province, shaped roughly like a rectangle 50 miles wide and 150 miles long, is situated near the geographic center of Oregon. A high plateau averaging just over one mile above sea level, it is bordered by three other provinces, the Blue Mountains to the north, the Basin and Range and Owyhee Uplands to the south and east, and the Cascade Range on the west. Within the narrow rectangle, Newberry Crater and Harney Basin form the west and east boundaries respectively.

The overall topography, as the name implies, is smooth, with moderate relief. Elevation ranges from a high of 7,984 feet at Paulina Peak to 4,080 feet above sea level in Harney Basin. The lack of deep canyons and gullies as well as a poorly developed network of streams are due to the low rainfall. Precipitation of only 10 to 20 inches a year in the plains regions is the result of the Western Cascade rainshadow. This minimal moisture has created an area of little vegetation which makes the High Lava Plains an outstanding region to see evidence of recent volcanic and tectonic activity producing features that are still "fresh."

The headwaters of the Deschutes River are along the western edge of the province, and most tributary streams are seasonal with poorly defined channels. Malheur and Harney lakes, the largest in the plains, collect the drainage of the Silvies River and Silver Creek from the north and the Donner and Blitzen River from the Steens Mountain to the south. These undrained basins contain playa lakes at certain times of the year. At the center of the broad Harney Basin, Malheur and Harney lakes are now nearly dry.



Geologic Overview

The High Lava Plains is a province of remarkable volcanic features, most of which are the result of relatively young eruptions. A multitude of volcanic cones and buttes, lava flows, and lava tube caves are scattered throughout the province. Except for deposits of talus, lake sediments, and fluvial debris, most of the rocks in the province are volcanic, and thick flows are not unusual.

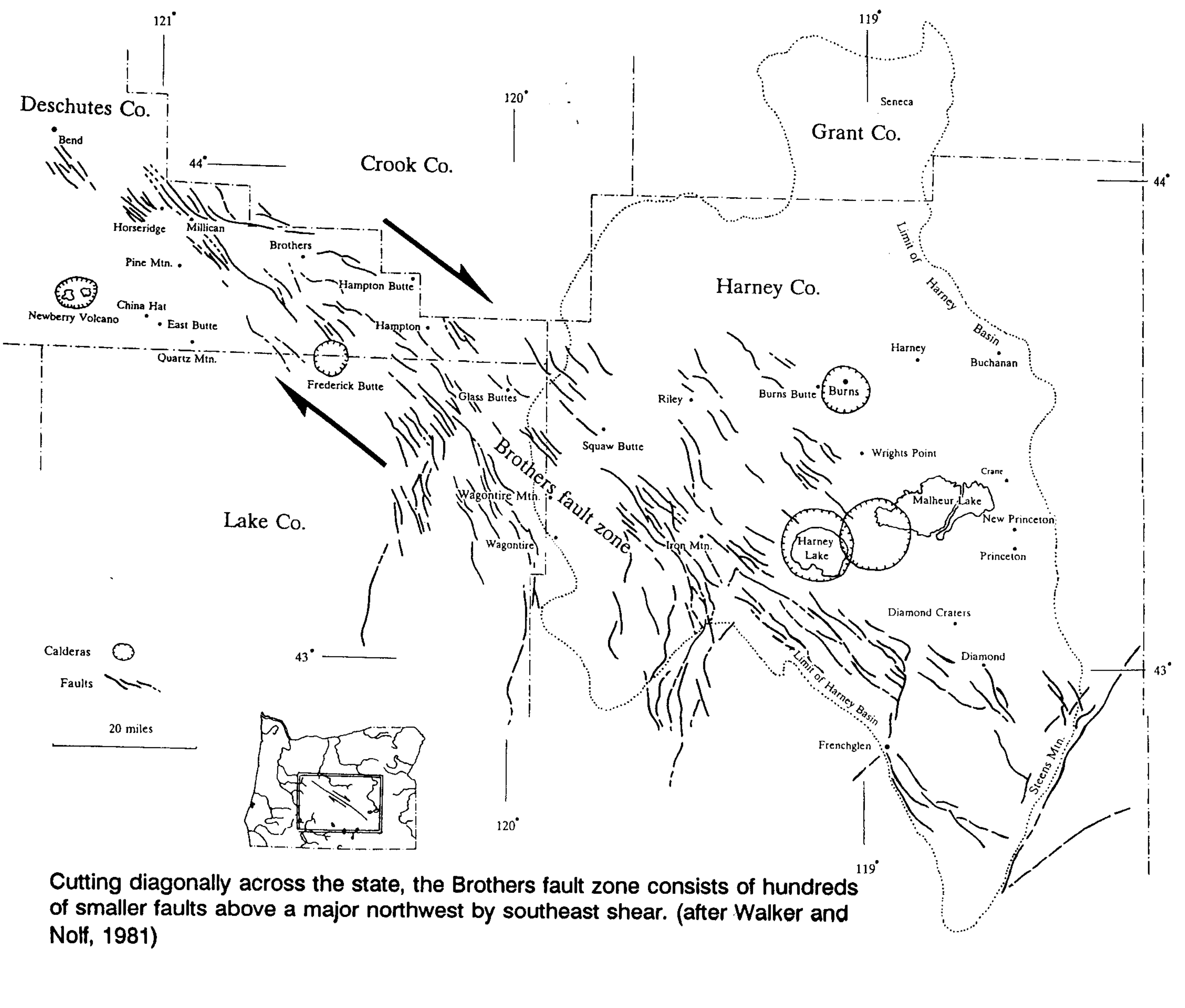
Volcanic eruptions of lava and ash beginning 10 million years ago continued into the Recent when vents along a zone of faults erupted with pumice, ash, and cinders along with thick viscous lava. The volcanic activity here relates to a broad zone of faults and fractures running across the province that resulted from two enormous, underlying crustal blocks wrenching past each other. Molten lava reached the surface by way of the cracks to ooze onto the surface as large and small volcanoes which are the hallmark of the province. These volcanic events produced some of the most interesting features of the High Lava Plains, where the immense shield cone containing Newberry Crater, small cinder cones, tuff rings, and explosion craters stand out on the flat plateau. Many recent lava flows enclosing trees created the unique Lava Cast Forest, while lava caves formed in hollow tubes within the cooling lavas.

Lakes that characterized the Great Basin during the Pleistocene filled many of the large depressions of the Lava Plains. With the Ice Ages broad expanses of the flat plains were covered with continuous shallow-water lakes that served as a habitat for mammals and birds. Throughout the province, these basins received both fluvial sediments and ash from contemporaneous volcanism until drying conditions reduced them to the playas found today.

Geology

Structurally the High Lava Plains blends with the Blue Mountains to the north and the Basin and Range to the south, but its volcanic characteristics set it apart. The oldest rocks exposed in the High Lava Plains province are Miocene lavas. Five to 10 million years ago the landscape here was dotted with erupting volcanoes and slow moving thick lavas spreading over the flat surface. One eruption followed the other almost continuously for millions of years. Eruptions aligned themselves in a broad belt of overlapping faults, known as the Brothers fault zone, the dominant structural feature of the High Lava Plains and central Oregon. The zone runs for 130 miles from Steens Mountain in southeastern Oregon to Bend. Within the Brothers fault zone, individual faults are irregularly spaced a quarter to 2 miles apart with modest displacements of less than 50 feet. Over 100 separate rhyolite volcanic centers are located along the belt of faults where the silica-rich lavas have exploited the fractures and fissures as avenues to reach the surface.

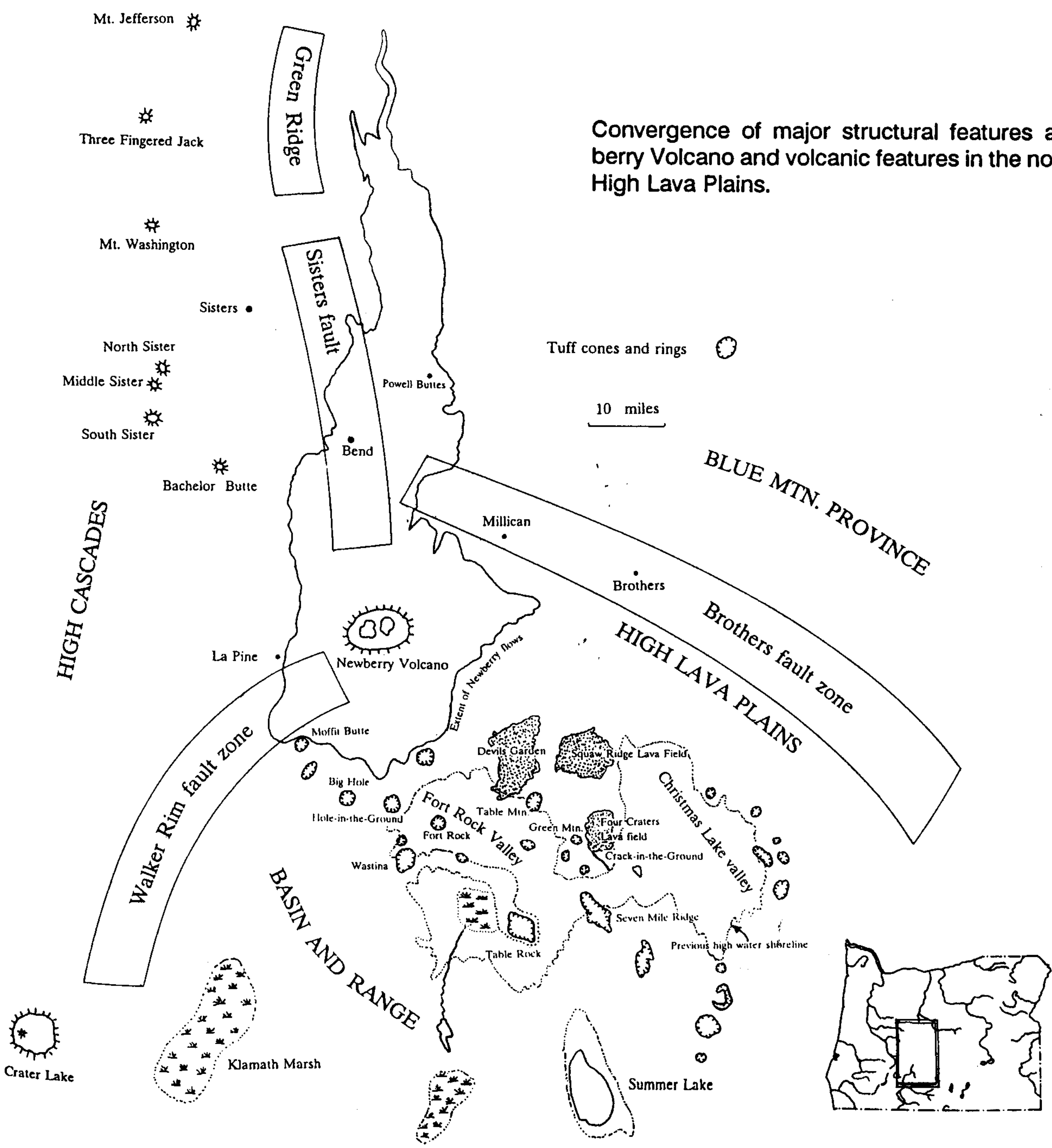
The Brothers fault zone was generated by the same forces that twisted Oregon in a clockwise motion throughout the Cenozoic era. Large tectonic blocks share a zone of weakness running north-south through central Oregon. As the blocks move relative to each other, the eastern block moved south and the western block moved north. Caught in the middle, central Oregon was distorted by wrench faulting expressed on the surface as the wide zone of faults. Most of the faults along the zone are so recent that they are easily seen in aerial photographs. Similar large-scale wrench faults in Oregon following the same northwest-southeast trend are the Eugene-Denio and Mt. McLoughlin faults to the south in the Basin and Range province.



Cutting diagonally across the state, the Brothers fault zone consists of hundreds of smaller faults above a major northwest by southeast shear. (after Walker and Nolf, 1981)

Newberry Crater, at the western edge of the province, is situated at the apex of three converging fault zones, the easterly Brothers fault zone, the northerly Green Ridge and Sisters fault zones, and the southwesterly Walker Rim fault zone. Placed at the center of these fracture patterns, it is little wonder that Newberry volcano formed as a separate, younger eruptive site well to the east of the High Cascade vents. Today a small magma chamber may be less than two miles below the caldera. Although it is often suggested that Newberry Crater may again erupt, its blanket of rhyolitic rocks tends to diminish that possibility, because silica-rich rhyolitic lavas ordinarily appear very late in the life cycle of a volcano.

Lavas of the High Plains are distinctly bimodal. That is, they have strikingly different compositions varying from dark-colored basalt to light-colored rhyolite. Basaltic lavas tend to have a deeper source in the crust and are extremely hot, while the lower temperature rhyolitic lavas are from chambers at shallow depths. In addition, basalts are generally an early stage of eruption, while rhyolites appear late in

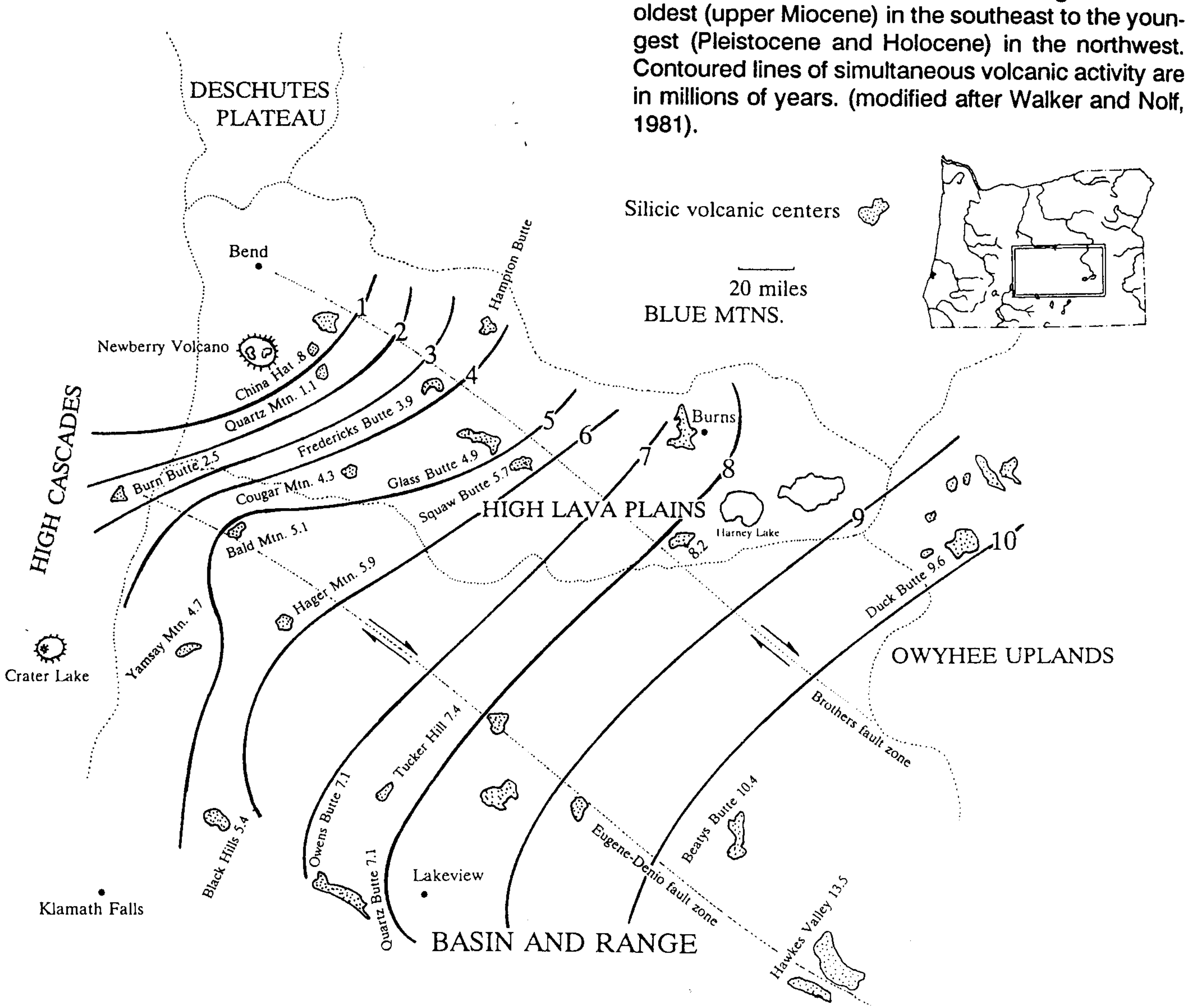


Convergence of major structural features at Newberry Volcano and volcanic features in the northwest High Lava Plains.

the cycle. In this province, the very fluid basaltic lavas predominate, but rhyolitic extrusions and domes are situated along major fracture zones. The association of basalt and rhyolite is is rare and usually occurs where the earth's crust thins because it is undergoing tension and being stretched.

Comparatively young eruptions and intrusions here between the upper Miocene and Recent occur in a broad northern belt of approximately 100 centers trending northwest across the Lava Plains and Owyhee Uplands. One of the most striking aspects of the High Lava Plains is the uniform decrease in the age of these volcanic eruptive centers geographically from east to west. Within the Harney Basin in the east, rhyolitic eruptions date back to 10 million years ago in the late Miocene, while near Newberry Crater in the west many lavas were extruded less than 1 million years ago. The eruptive zone moved steadily from the southeast toward the northwest at slightly more than one mile per 100,000 years. Such a progression of eruptions might be seen as an earth crustal plate moving over a hot spot, but two important aspects of local geology seem to preclude this notion.

First, it is well established that the North American plate, upon which this province rests, has moved progressively westward since well before Miocene time. The age progression should then be reversed with younger volcanics appearing in the east instead of in the west, as is the case with the Yellowstone hot spot. Additionally, another broad belt of rhyolitic and silicic domes to the south in the Basin and Range province between Beatys Butte in the southeast and



Age progression of silicic volcanic centers in the High Lava Plains and Basin and Range from the oldest (upper Miocene) in the southeast to the youngest (Pleistocene and Holocene) in the northwest. Contoured lines of simultaneous volcanic activity are in millions of years. (modified after Walker and Nolf, 1981).

Yamsay Mountain to the northwest displays a similar age progression from east to west suggesting the deep magmatic source feeding these volcanic centers is a wide linear front. This age progression could relate to the clockwise rotational movement of central Oregon resulting from plate movement and Basin and Range extension. As the Basin and Range crust thins and stretches, differential movement with a center of rotation to the south could yield this age progression. More than likely, however, the age progression may be due to a steady steepening of the subduction zone known to be below eastern Oregon at this time. As the subduction of the Farallon plate slowed down, the descending slab angled more steeply below the North American plate. The eruptive front then moved westward which maintained the usual 90 mile distance between the melting rocks and eruptive volcanoes on the surface.

Pleistocene Lakes

During the late Pleistocene, up to 11,000 years ago, large and small lakes characterized the Great Basin in Oregon, Nevada, and Utah. Within the Great Basin, tensional faulting yields a basin and range topography, where today the shallow basins are either lakes or dry playas. The southern portion of the High Lava Plains merges gradually with the northern Great Basin and includes such lakes as those which once occupied the dry basins of Fort Rock Valley, Christmas Lake Valley, Silver Lake, and Fossil Lake situated south and southeast of Paulina Mountains. Prehistoric Fort Rock Lake, covering 1,400 square miles, was the largest of these followed by Malheur Lake at 900 square miles.

The sediments of ancient lakes in the High Lava Plains provide an outstanding record of Ice Age mammals as well as the activities of early man. Filled with broad expanses of water during the Pleistocene, the lakes and shores served as a habitat for mammals and waterfowl of every description. Pollen and plant fossils recovered from the former lake sediments reflect a lush Pleistocene vegetation that supported these large animals living along the margins of the lakes. Today these lake sands yield not only fossil vertebrate remains but worked flint tools and pottery from the Indians who hunted there. Early accounts mention that wagon loads of fossil bones were collected and removed from Fossil Lake where bird, fish, and mammal bones all have the distinctive, shiny black patina of desert varnish.

During highwater periods of the Pleistocene, Silver Lake, Christmas Lake, Fossil Lake, and Fort Rock Lake were interconnected, the contiguous broad lake reaching a maximum depth of over 200 feet. Some of the higher elevations as Fort Rock were islands. During more arid intervals, islands became peninsulas, arms of the lake became bays, and with further drying bays became isolated marshes and swamps. Blowing winds made shallow depressions that became ponds during wetter, cooler climatic stages.

Old shorelines of Fort Rock Lake are easily recognized today by tracing gravels and beach erosion, however, 30,000 year old shorelines are obscured on the north by younger fresh lava flows in the vicinity of the Devils Garden. Postulated maximum shorelines are several hundred feet lower than river divides to the north. If the lake drained north to the Columbia, the former channel is probably covered by the younger lavas. Bones of the andromous salmon and the presence of a small snail, Limnaea, found at Fossil Lake, are known only in Columbia River drainage and point to the existence of a former outlet to the north. Dry River, that occupies a narrow canyon at the east end of Horse Ridge along Highway 20, may have been carved at the time some of the interior basins, perhaps Fort Rock Lake, overflowed making its way to Crooked River and then by way of the Deschutes River to the Columbia.

Harney Basin

The largest closed depression in the province, Harney Basin, is situated on the southeast corner of the High Lava Plains. Sitting directly upon the Brothers fault zone, the basin extends north and south well beyond the limits of the Lava Plains province. At 5,300 square miles, the depression is larger than the state of Connecticut. Harney Basin began to evolve as a downwarp assisted by large calderas which collapsed within the depression into an evacuated magma chamber. Large-scale eruptions of as much as 500 cubic miles of rhyolite accompanied the development. Today there is no surface outlet to the basin, and Harney, Malheur, and Mud lakes occupy the central southern part of the depression.

Throughout the later Cenozoic, the Harney Basin received lava flows, ash flow tuffs, and tuffaceous sediments derived from the surrounding volcanic activity. Miocene basalt from Steens Mountain was followed by air-borne pyroclastic material and ash-flows of the Danforth and Harney formations. Ash-flow tuffs of the former Danforth have been divided into the Devine Canyon, Prater Creek, and Rattlesnake members that form distinctive stratigraphic layers that can be traced and easily recognized over vast regions of southeast Oregon. The greenish-gray Devine Canyon extends from Steens Mountain in the southeast as far as Paulina Valley in the northwest, whereas the Prater Creek ash-flow tuff is limited to exposures in the

Harney Basin. The remarkable Rattlesnake ash-flow tuff, which extends to the vicinity of John Day 90 miles to the north, also has source vents in the Harney Basin. These formations are covered by alluvium and lake deposits eroded largely from the volcanic rocks of the adjacent uplands. At the outer margins of the basin, sand and gravel predominate, while silts and clays fill the center. Younger lavas from Diamond Craters along with some Pleistocene basalts cover these sediments. Within these deposits thin but well-defined layers of 6,900 year old Mazama ash lie three to six feet below the surface.

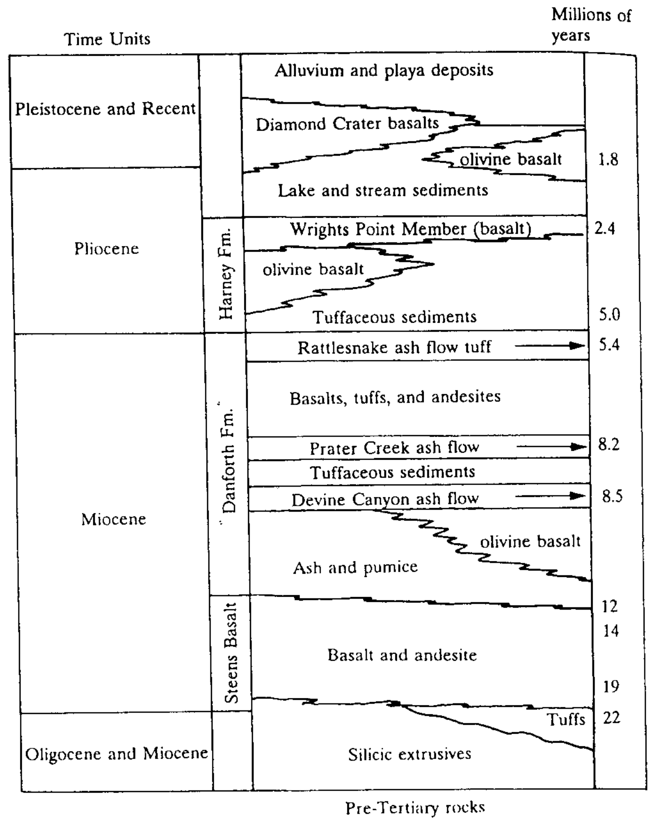
Shallow, ephemeral Malheur and Harney lakes, and smaller Mud lake which connects the two, are located in the south central portion of Harney Basin. During wetter conditions existing in the Pleistocene, a huge body of freshwater, ancient Lake Malheur, occupied the basin and extended all the way to Burns. The lake originally drained to the east along the south fork of the Malheur River and from there to the Snake River until the outlets near Princeton and Crane were dammed by a lava flow. As warmer, dryer conditions prevailed, about 10,000 years ago, the lake rapidly shrank in size creating the present series of smaller lakes, playas, and marshes. Lake Malheur, at its highest water level, was probably never more than 50 feet deep.

Even historically Malheur, Mud, and Harney lakes were not always joined. Explorer Peter Skene Ogden observed in 1826 that "*a small ridge of land, an acre in width, divides the freshwater from the salt lakes*". About 1880 Malheur Lake topped the ridge and overflowed into Harney Lake. Today these lakes frequently double or triple in size during wet spells or decrease to virtually nothing in a dry period. Flooding during three years of record rainfall in 1984 caused the three lakes, normally covering 125,000 acres, to expand to 175,000 acres. Periods of extreme drought are not abnormal to these lakes, and prior to 1930 they became virtually dry due to low rainfall.

Malheur, Harney, and Mud lakes have been designated as the federal Malheur National Wildlife Refuge, a home for thousands of wild birds, native plants, and animals.

Geothermal Resources

Percolating from deep within the crust through cracks and fractures, heated water reaches the surface as warm springs. Scattered over the Harney Basin, almost all thermal springs are aligned along faults. Although some springs record much higher readings, the average temperature of the waters is between 60 and 82 degrees Fahrenheit. Thermal waters, ranging from 64 degrees to 154 degrees Fahrenheit issue from a number of perennial springs near Hines, Warm Springs valley east of Burns, and around Harney and Mud Lakes to the south. Water temperatures near Hines reach a high of 82 degrees Fahrenheit with temperatures diminishing outward from there. Some of the highest temperatures occur in spring waters southwest of Harney Lake where 90 to 154 degree Fahrenheit waters indicate the presence of a thermal system. Several springs here have commercial facilities, and one, Radium Hot Springs, popular since the 1890s, is the largest warm water pool in the state.

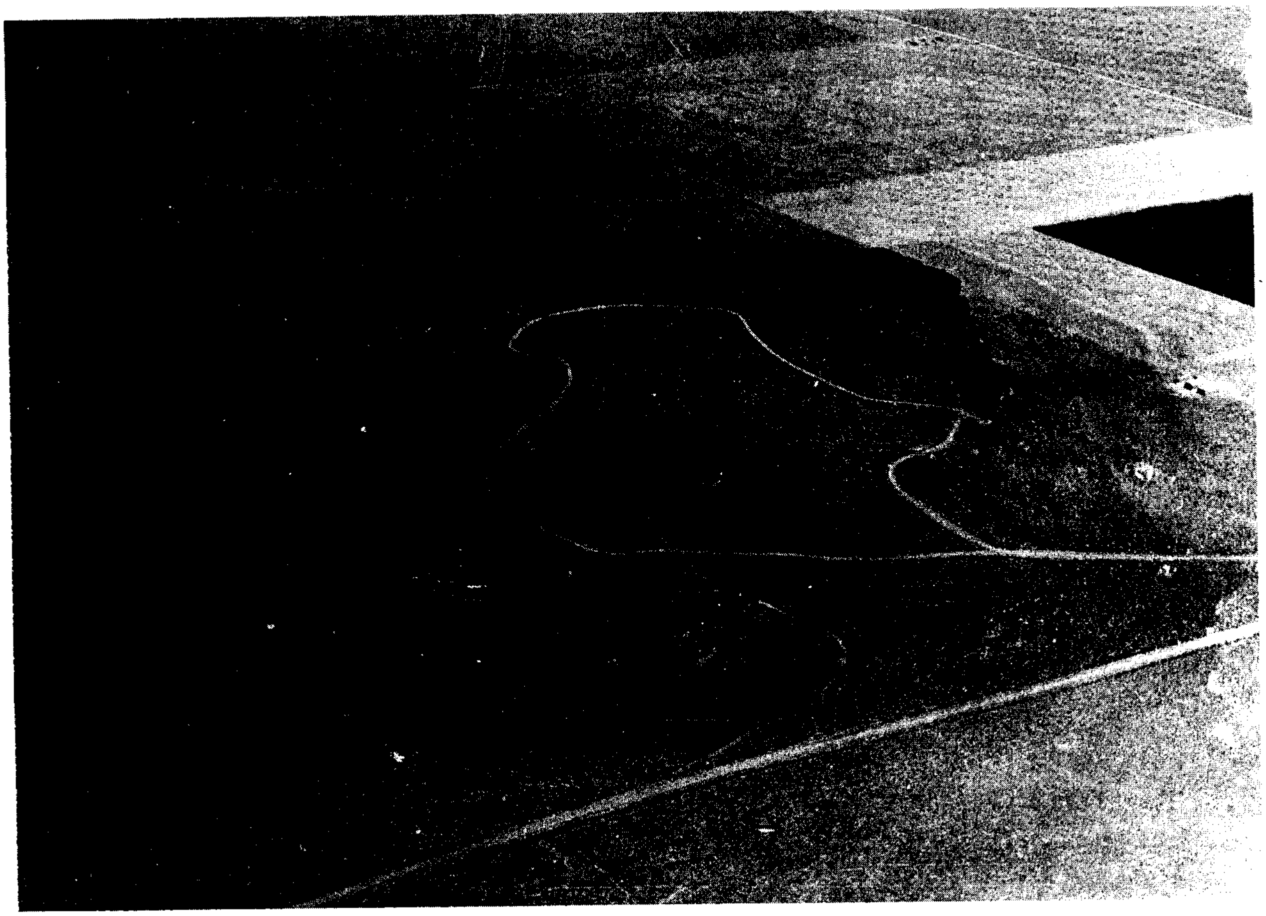


Correlation chart of High Lava Plains stratigraphic units

Features of Geologic Interest

Fort Rock, Hole-in-the-Ground, Big Hole

Distributed widely on the High Lava Plains, maars and tuff rings resulted when upward moving lava in the crust encountered underground water with devastating effects. Upon contact with the cooler water, the hot lava exploded catastrophically, creating a symmetrical, circular crater. Rocks and ash from the eruption, thrown into the air, settled close to the crater building up a high rim or tuff ring. Saucer-shaped maars are shallow explosion craters that are fed by a



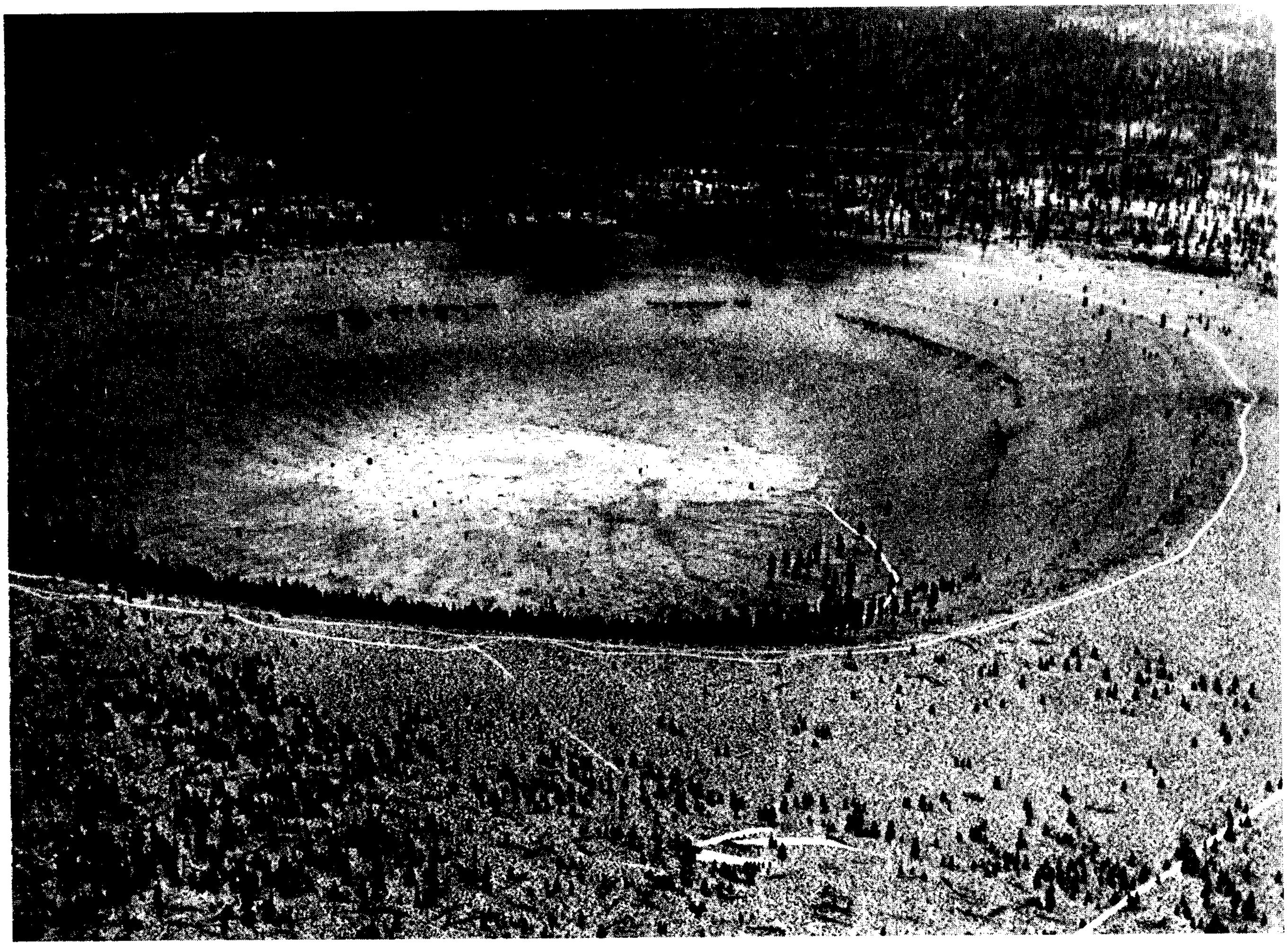
In northern Lake County, Fort Rock is a tuff ring eroded by waves of a shallow Pleistocene lake that once occupied this basin (photo courtesy Oregon Dept. Geology and Mineral Industries).

"diatreme" or funnel-shaped vent which ultimately fills with angular pieces of volcanic breccia. Often these surface landforms are covered or eroded and not fully preserved. Three concentrations of tuff rings and maars in Oregon are located in northern and southern Lake County and in southern Klamath County. The best-known of these are Fort Rock, Hole-in-the-Ground, and Big Hole.

In Lake County, Fort Rock is a crescent-shaped tuff ring 1/3 mile across and 325 feet above the surrounding flat plains. Formed by a shattering explosion in early Pleistocene time, the crater has steep rock sides resembling a fort or castle. Once past the initial violent stage, the dying crater lacked the force to expell the ash, and much of it fell back within the ring where the yellowish and brown tuffs dip inward toward the center. Broken rock, ash and explosion tuffs that make up the crater walls are testimony to the extreme force of the Fort Rock event. The unusual shape of Fort Rock, with the wide breach in the south rim, was due to wave action from a former lake here eroding the thin walls of the ring.

Hole-in-the-Ground, a short distance north of Fort Rock in Lake County, is an explosion crater of remarkable symmetry. The pit is almost a mile in diameter, and the floor is over 300 feet below the surrounding land level. The bowl-shaped maar probably resulted from a single or very brief series of violent eruptions over a short period of time. Fine rock material expelled by the explosion forms the crater ring and floor. Drilling in the late 1960s has revealed buried massive blocks of broken rock which fell into the maar after the explosion.

To the northeast, Big Hole, a little over one mile in diameter is a circular maar created by a similar violent explosion. A wide ledge within the basin may be

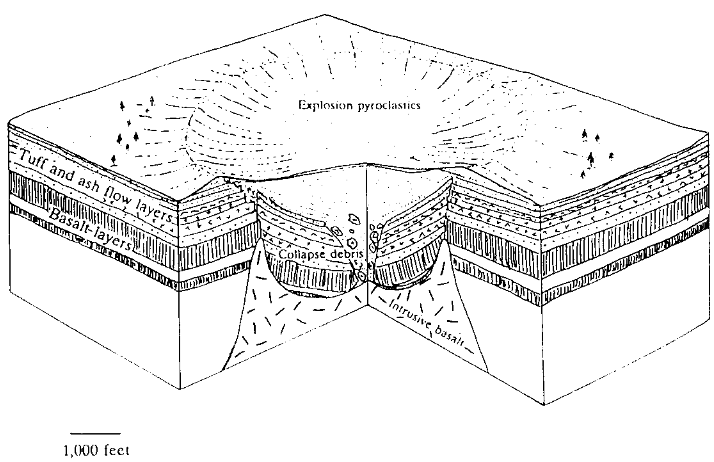


Hole-in-the-Ground, near Fort Rock, is a remarkable explosion crater (photo courtesy of Oregon Dept. Geology and Mineral Industries).

the top of a large block which fell into the depression during the eruption. Unlike Fort Rock and Hole-in-the-Ground, Big Hole is heavily forested. The trees and its immense size make this volcanic feature difficult to visualize from the ground level.

Four Craters, Devils Garden, and Squaw Ridge Lava Fields

Continuing Pleistocene volcanic activity in the eastern High Lava Plains resulted in a number of unusual lava flows, domes, pumice and cinder cones, and lava tubes at three locations in Lake County. At Four Craters Lava Field on the northern edge of Christmas Lake Valley, four cinder cones with smaller mounds are surrounded by lava flows emitted from vents aligned along a fissure. Here blocky and broken aa lava from the cones covers about 12 square miles. Nearby Devils Garden and Squaw Ridge lava fields are

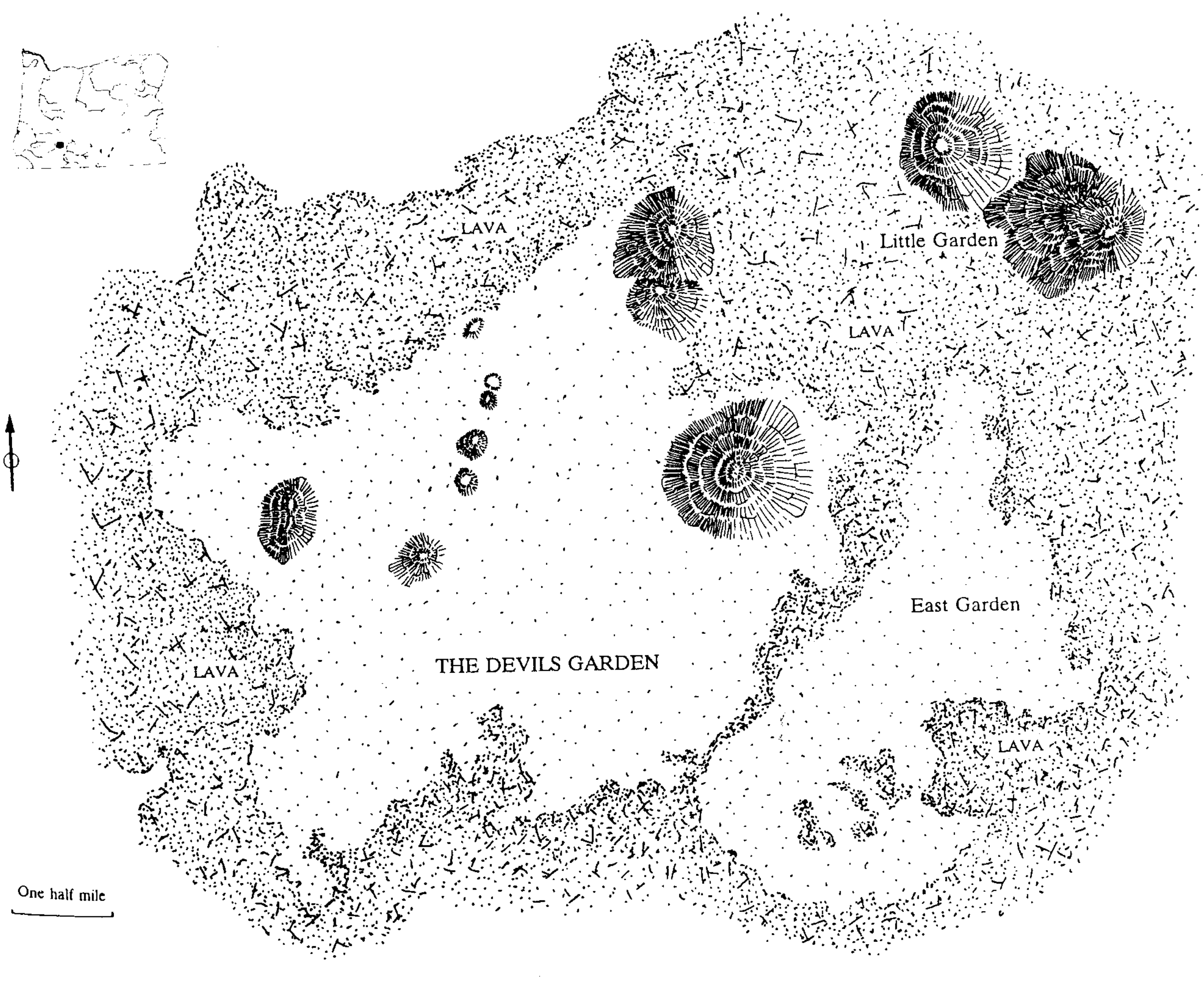


At Hole-in-the-Ground, the collapse blocks and crater rim are overlain by a thick layer of ash and tuff. (modified after Peterson and Groh, 1961) large areas of clinkery chunks of broken aa lava and black swirly pahoehoe lava. Oozing from fissures, several large spatter cones were built up by cooling lava. Flows from the shallow Squaw Ridge cone covered over 200 square miles, while the adjacent Devils Garden is 45 square miles of lava, rubble, ash, basaltic bombs, and lava tube caves. Numerous small caves were formed by molten lava streams. In one of these, Derrick Cave, a collapsed roof forms the entrance. At spots along the tunnel of the cave, the roof rises as high as 50 feet. Benches inside the lava tube give the cave a keyhole-shape in cross-section to show that the lava drained out slowly enough to leave behind a lining along the wall.

Diamond Craters

To the south and east of the lava fields near Bend, Diamond Craters in Harney County is one of the most dramatic of Oregon's volcanic attractions, displaying a varied landscape produced by late Miocene to Pleistocene eruptions. Named for the diamond-shaped cattle brand of an early settler, the craters are easy to reach. Within a 22 square mile natural area south of Malheur Lake, over 100 cinder cones and craters can be seen, 30 of which are located inside a 3,500 foot wide caldera which has collapsed to a depth of 200 feet.

About 9 million years ago vents here pumped out ash and lava to cover 7,000 square miles of southeast Oregon in layers up to 130 feet thick. This initial activity was followed by a series of explosions and intrusions 2,500 years ago forming small cinder cones accompanied by vast new lava flows. A surge of mag-



The Devils Garden offers 45 square miles of rough black lava flows, spatter cones, and lava tubes in northern Lake County.

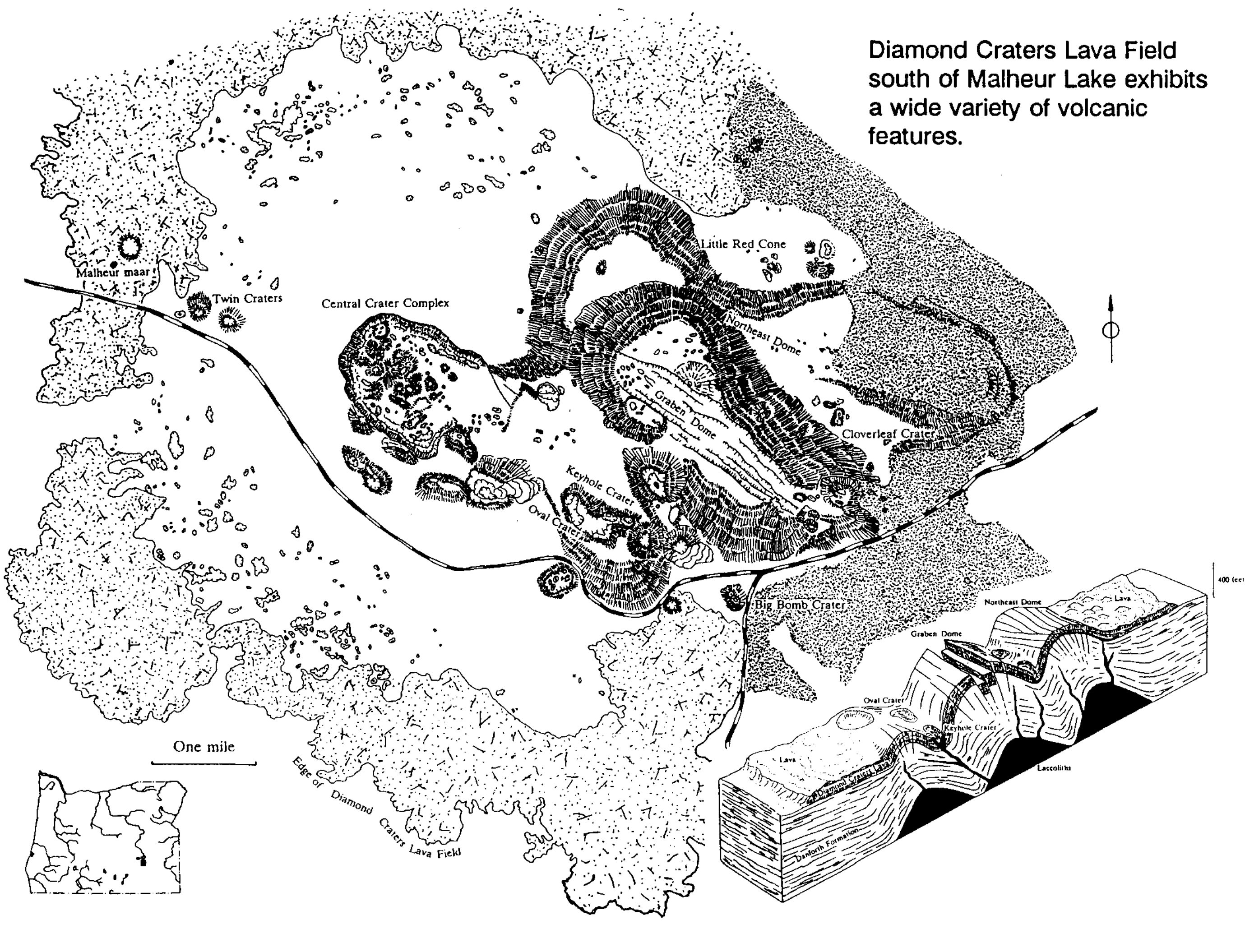
The central crater complex about one mile in diameter is a moonscape of overlapping volcanic features (photo courtesy Oregon Dept. Geology and Mineral Industries).

matic intrusions bowed the ground surface into several low rounded domes. One of the eruptions produced spherical-shaped volcanic bombs along with flows of pahoehoe lava that created deep fissures and ridges. These bombs ranging from the size of a pea up to 2 feet in diameter were ejected as air borne blobs of liquid lava that cooled and cracked in flight. A more dramatic result of these volcanic events is the large depression or Graben Dome, 7,000 feet long, 1,250 feet wide, and 100 feet deep that developed as lava drained away underground causing the upper surface of the crater to collapse and create a basin.

Volcanic Buttes, Lava Cast Forest, Newberry Crater

Cinder and basalt cones stand out on the flat landscape near Bend and along the route from Bend to Burns. The most notable of these are Pilot Butte just east of the Bend city limits, Powell Buttes to the northeast, Newberry Crater and Lava Butte to the south, and Glass Buttes to the east.

Pilot Butte, a prominent feature in central Oregon, served as a landmark for pioneers travelling to the Willamette Valley. A view atop the lone cinder cone, 4,136 feet above sea level and 500 feet above the



Diamond Craters Lava Field south of Malheur Lake exhibits a wide variety of volcanic features.

In the Lava Cast Forest on the northwest flank of Newberry Crater, lava has surrounded trees which burned to leave a hollow mold (photo courtesy of Oregon State Highway Department).

surrounding plains, offers an impressive panorama of the Cascades and surrounding buttes of the High Lava Plains, as well as a glimpse of the winding canyon of the Deschutes River. Volcanic debris, discharged from a vent into the air, settled as cinders and ash to build up the symmetrical cone. Pilot Butte has been a state park since 1927.

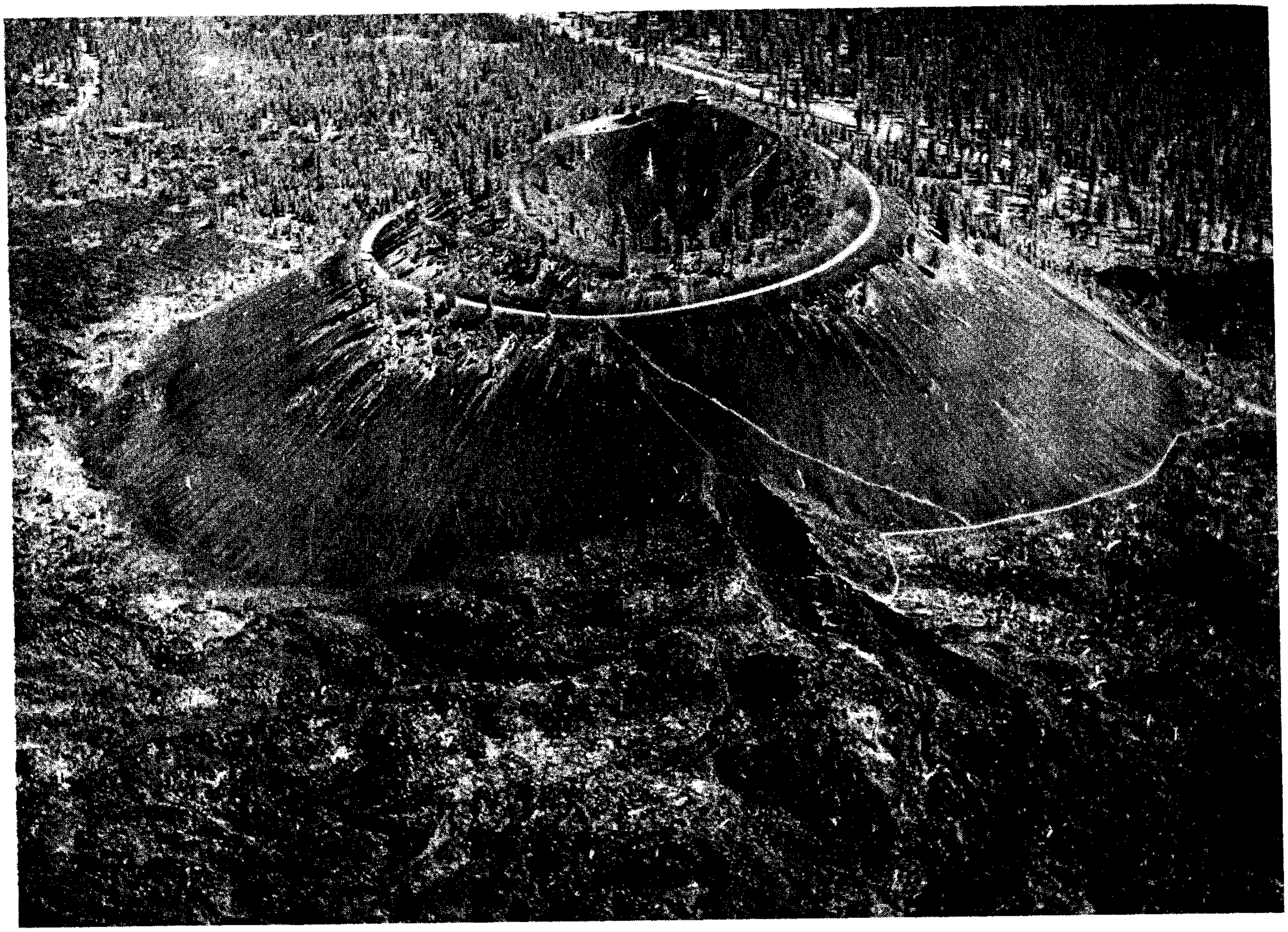
Nearby Powell Buttes complex of 11 separate volcanic domes represents a major silicic volcanic center that expelled large volumes of lava and ash-flow tuffs during the Miocene. Domes formed during the final stages of activity and subsequent erosion produced remnants known as "hat rocks". Exploratory geothermal tests have located warm water wells on the north side of Powell Buttes.

Lava Butte, familiar to anyone who has travelled south of Bend, is a classic basalt cinder cone projecting 500 feet above the surrounding jagged lava field. Because it is situated on the flank of Newberry Crater, Lava Butte is a "parasite cone" and is part of an almost continuous wide zone of faults and cracks extending from Newberry Crater to Lava Butte and beyond. More than 6,000 years ago, lava extruded from these vents in at least eight separate eruptive events, flowing northwesterly for 6 miles to dam and divert the Deschutes River. From the rim of the deep crater, built up by cinders, a rugged volcanic panorama covering almost 10 square miles of lava field can be seen.

As successive, thick flows from this volcanic center between Newberry Crater and Lava Butte spread sluggishly across the landscape, pine forests much like those here today were engulfed by the slow moving lava. Some trees remained upright while others fell over after being buried by the molten lava. Once enclosed in the flow, the trees burned slowly leaving a mold the size and shape of the trunk. Contact with the trees chilled the lava in the flow into cylinders around trunks. Once the lava had receeded, these cylinders were left standing above the surface flow. The Lava Cast Forest which resulted is encased in the rough black lava.

Newberry Crater, with a large caldera, lakes, obsidian flows and domes, and pumice and cinder cones, provides a view of spectacular volcanic geology in a concise area that is easily accessible. In the spring of 1991, Newberry Volcanoes National Monument was dedicated. This new monument which includes Newberry Crater, Lava Butte, Lava River Cave, the Lava Cast Forest, and Paulina Peak sets aside an area for viewing and studying a wide variety of volcanic features.

A low profile, shield volcano, Newberry is 40 miles long and 20 miles wide and contains Newberry



A cinder cone just south of Bend, Lava Butte has a well-developed crater on top and a vent which extruded lava on the south side (photo courtesy of Oregon Department of Geology and Mineral Industries).

Crater at the summit. Covering 500 square miles, the volcano is among the largest Quaternary volcanoes in the United States. The caldera was caused by collapse or sinking of the center of the mountain in somewhat the same manner that the caldera formed at Crater Lake. Today the central caldera is occupied by East and Paulina lakes which are separated by cinder cones and a massive obsidian flow.

With a comparatively short eruptive life lasting around 1/2 million years, the active period of Newberry volcano spans that of Crater Lake 70 miles to the southwest. About 500,000 years ago, a huge shield volcano, 4,000 feet above the surrounding plateau, was built by successive flows of basalt and silica-rich rhyolite interspersed with layers of volcanic ash, dust, and consolidated tuffs. The summit of the volcano may have collapsed at least twice after two large eruptions to create the caldera. Continued intermitent activity produced small domes, lava flows, and obsidian 300,000 to 400,000 years ago that was followed by a huge ash eruption about 1600 years ago. Most recent activity began 2,000 years ago when lava discharged from a fracture on the south rim of the caldera spreading about 1 1/2 miles toward the center. This striking Big Obsidian flow is the largest of several young flows in the crater producing over 1/2 cubic miles of frothy pumice, ash, and obsidian as well as the dome marking the vent. A distinctive 6,900 year old layer of pumice and ash from ancient Mt. Mazama is laminated in among Newberry's own eruptive debris. Near the end of the cycle more than a half dozen separate obsidian flows, interlayered with a volcanic froth or pumice, spread out within the caldera.

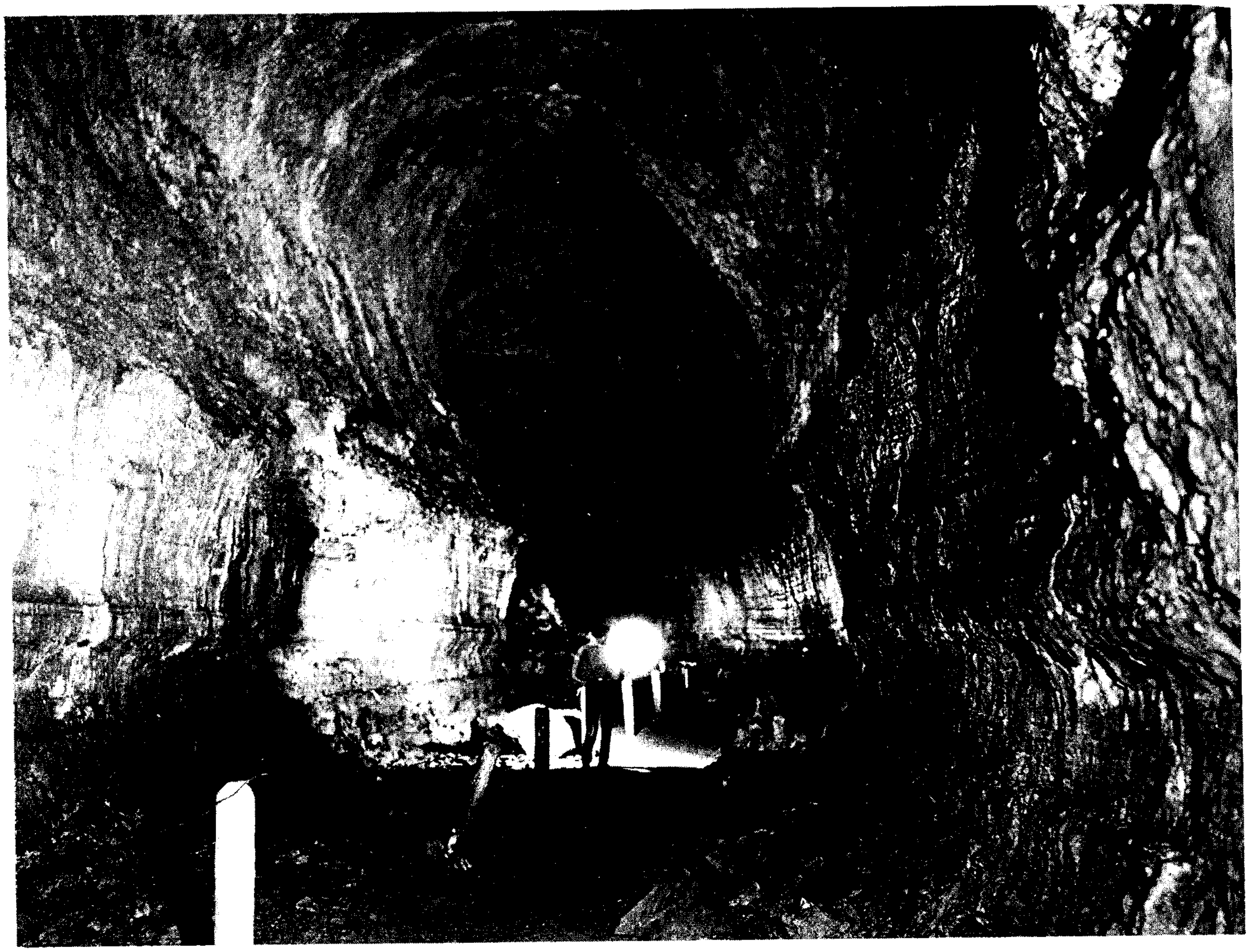
The long outer slopes of the volcano are sprinkled with over 400 parasitic cinder cones, some in regular lines, indicating alignment along fractures. Nineteen rhyolitic domes, flows, small explosion

Newberry Volcano moument, covering 62,000 acres south of Bend, provides a panorama of forests, lava flows, volcanic cones, lakes, and craters.

craters, and other features on the flanks occur in zones radial to the caldera. Basalt flows, forming most of the north and south flanks, are younger than the ash flows of the east and west flank which are covered by a thin veneer of ash. Paulina Creek drains the caldera, dropping over the west rim as Paulina Falls to flow westward into the Deschutes River.

Over the past decade Newberry Volcano has been the site of intensive investigation for its geothermal potential, and drilling has encountered an active hydrothermal system beneath the caldera. The recognition of the delicate ecological balance here should eliminate any future exploitation at this site.

Glass Buttes east of Newberry Caldera is a 5 million year old silica-rhyolite volcanic center consisting of Glass Butte, Little Glass Butte, eastern Glass Buttes, and Round Top Butte.The low domes aligned in a west-northwest direction for about 12 miles built up in a long eruptive process which may have taken as much as 1 million years to complete. The Glass Buttes group produced significant amounts of obsidian which was gathered by Indians in prehistoric times and more recently by rock collectors. Besides the common black obsidian, there are mixtures of red and black as well as iridescent silver obsidian. Obsidian or volcanic glass has no internal crystalline structure. The failure to form crystals may be due to the exceedingly high viscosity prior to cooling. Very small amounts of quicksilver have been mined from the volcanics of Glass Buttes.



In Lava River Cave south of Bend the lava remained molten while the roof and sides solidified. Flowing out, the lava left flow lines, benches, and a keyhole-shape to the sides of the tunnel (photo courtesy of Oregon State Highway Department).

Lava Caves

A number of caves and long cavern systems exist in the Bend area as a result of volcanism which took place during the Pliocene and Pleistocene throughout the western High Lava Plains. Tubes and tunnels in basalt occur as molten lava cools to form a solid crust on the surface even as the hot lava stream continues to run out deep in the flow. As volcanic activity producing the lava ceases, the tube is drained leaving the cave or cavern. Tubes usually form when lava is thick and syrupy, and caves are most common in pahoehoe flows. Wide lava sheets often have several tubes within the flow, some of which may be interconnected by lateral passages. Pahoehoe lava, flowing through a narrow valley, will ordinarily produce only a single tunnel or a series of tubes which are stacked up over each other.

The pathway of lava caves are variously straight to meandering. Straight caves follow old fault and fracture patterns. More often, however, lava caves follow the twisting pathway of an ancient stream channel cut into the surface and filled in by lava. As the lava smoothed out the older topography, the thicker flows along stream channels remained liquid to drain out while the roof hardened. After the lava tube has formed, weathering processes attack the roof, leading to collapse, and producing cave openings.

Historically lava caves were used for shelter by Indians and early settlers. Eastern Oregon ranchers often kept meat chilled in caves which maintain a temperature of 40 degrees Fahrenheit year round. In the early part of the century, large blocks of ice were cut from Arnold Ice Cave to supply the nearby community of Bend on a commercial basis. One unusual advantage settlers found for the caves near Bend was as a place to brew whiskey. Federal agents conducting monthly raids, as the one in January, 1921, confiscated 2 stills, 3 quarts of whiskey, and several barrels of corn mash. Once raided, the caverns were sealed.

The Arnold Lava Cave system extends northeasterly from Paulina Mountains over 4 miles. In a number of places the roof has collapsed producing a series of smaller caves. This long lava channel system formed in basalt originating from fissures on the flanks of Newberry caldera. At the southwest end of the Arnold cave system is the well-known Arnold Ice Cave. Within the cave, water cascading down the walls freezes into silent waterfalls. Where the cave intersects the water table, ice forms. Since the water level is rising, ice now covers a stairway once in use, so that special climbing equipment is needed to enter the cavern.

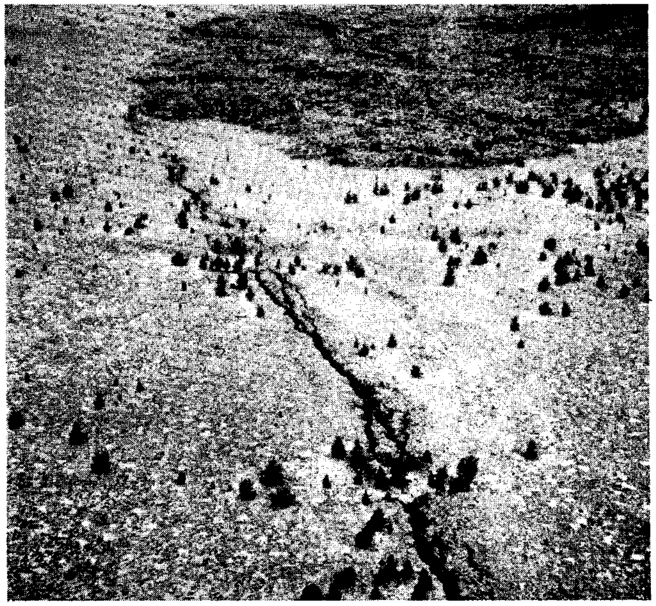
Southwest of Arnold Ice Cave, the famous mile-long Lava River Cave, formerly known as Dillman Cave, is one of the longest, uncollapsed lava tubes in Oregon. Leander Dillman, trapper and rancher, discovered the southeast entrance about 1909, but when he was convicted of "gross immorality" in 1921 the name was abruptly changed. Entered where the roof has collapsed, the main passageway of the cave is 5,040 feet to the lower end which is blocked by sand. Delicate lava formations, vertically stacked lava tubes, ledges marking the levels of lava that flowed through the tube, and unusual sand castles where surface water drained down through the tube to carve out the sands into a miniature badlands make the cave of geologic interest.

Lavacicle Cave, south of Millican in Deschutes County, is best known for its unique spikes of lava hanging from the ceiling of the tunnel and projecting up from the cave floor. Discovered in 1959 and named for these unusual formations, the cave was once filled to the roof with molten lava. Once the lava had drained out, the material coating the ceiling of the cave dripped to the floor forming the pinnacles, called lavacicles. Lavacicles from the ceiling are only a few inches long, but those projecting from the floor are 2 to 6 feet in height. Because of the fragile formations, the cave entrace is barred and permission to enter must be obtained from the U.S. Forest Service.

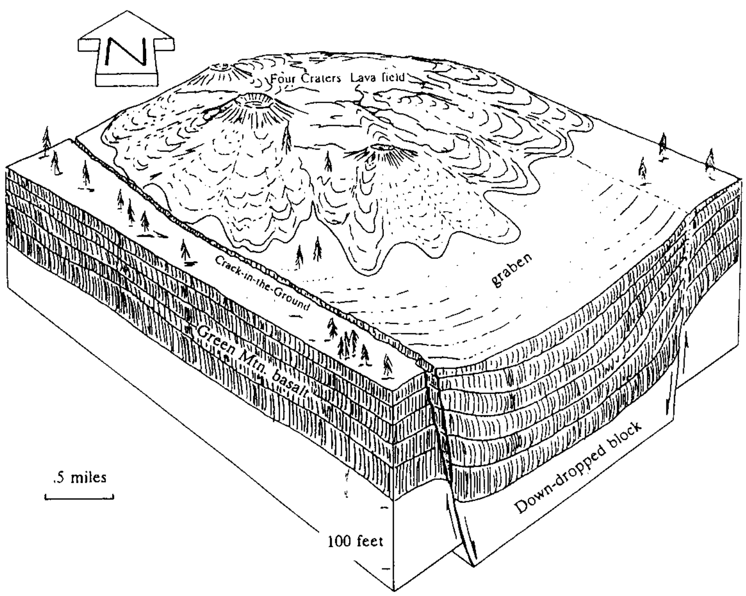
On the extreme eastern edge of the Lava Plains, privately owned Malheur Cave is difficult to locate. At least one-half of the cave is filled with water creating a long underground lake where the lava tube intersects the ground water table. The cave must be explored by canoe or raft, although the lake waters and configuration of the tunnel prevent passage after a certain point.

Crack-in-the-Ground

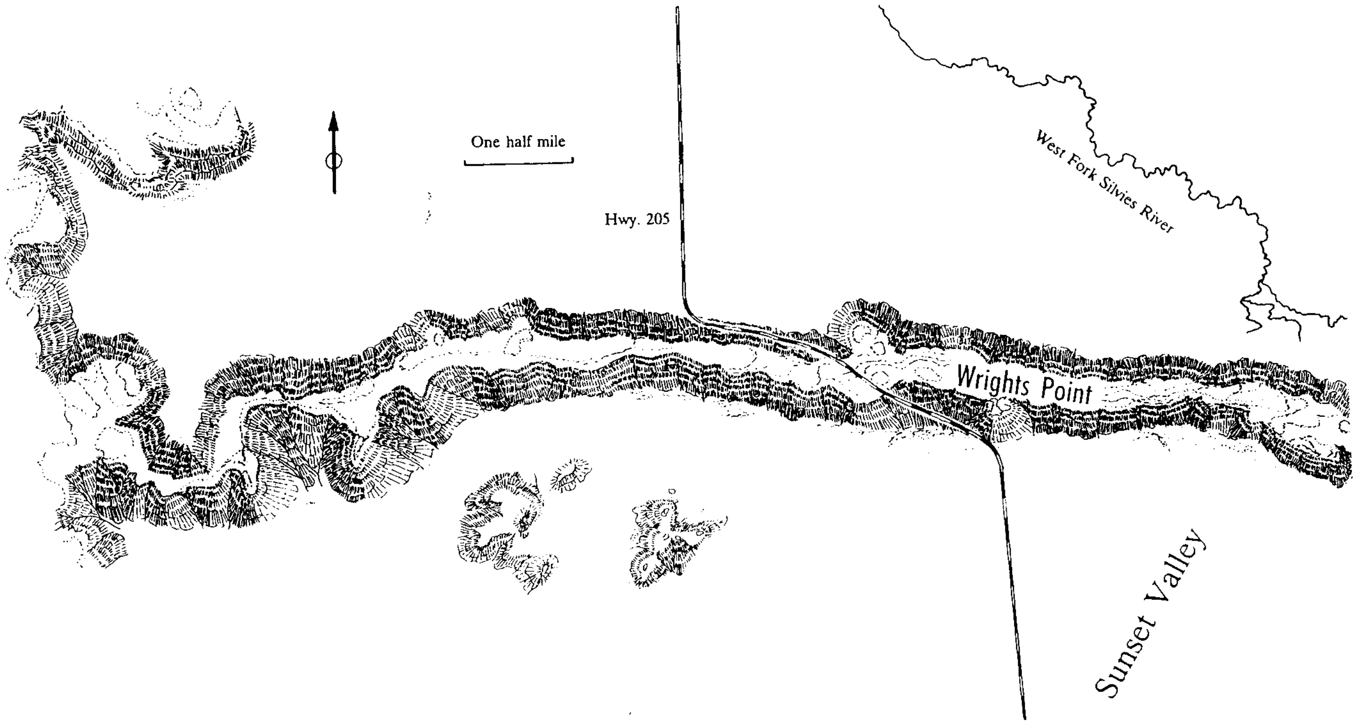
A narrow northwest-southeast rift in the ground a few feet wide, 2 miles long, and up to 70 feet deep in places has remained open for several thousand years. Located in Lake County between prehistoric Christmas Lake to the south and the Four Craters lava field to



Crack-in-the-Ground from the south with Four Craters Lava Field in the background (photo courtesy of Oregon Department of Geology and Mineral Industries).



This narrow, two mile-long crack in Lake County opened in layers of lava when a block beneath the flow dropped down. (after Peterson and Groh, 1964)



the north, this feature was referred to as "the crack" by homesteaders. Here picnics were held and ice cream made using ice deep from within the crevasses of the chasm.

During the Pleistocene successive flows of pahoehoe lava here piled up 70 feet thick in places, only to be covered later by streams of hummocky black aa lava. These basalts originated from Green Mountain and the Four Craters volcanoes. With the Four Craters eruption, a small tectonic depression or graben appeared about 2 miles wide extending south into the Christmas Lake basin. Crack-in-the-Ground opened in the lavas when the central block began to drop down to create the graben and trigger the crack seen on the surface. In a wetter environment than eastern Oregon, such geologic features would have been rapidly filled in with sediment and rubble or covered by vegetation.

Wrights Point

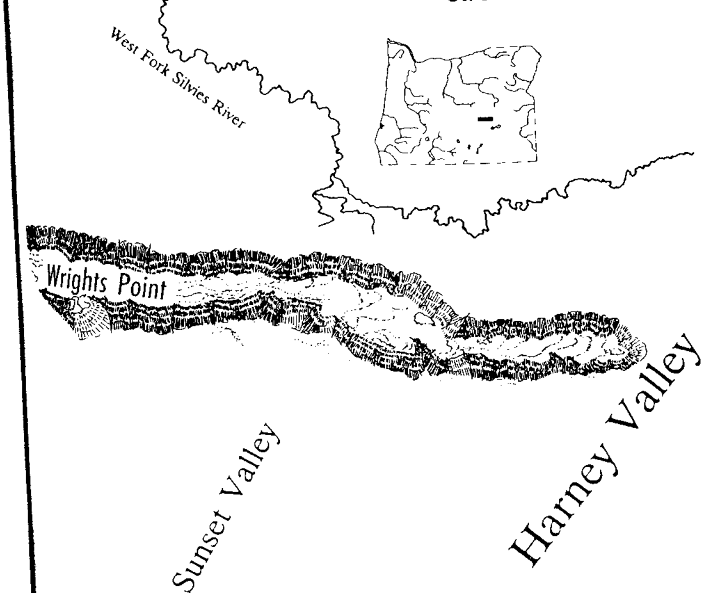
Lava flows following a prehistoric stream bed have created a 150 foot high sinuous ridge named Wrights Point 12 miles south of Burns. Extending a distance of 6 miles, the flat-topped ridge averages 400 yards wide before it merges with a broad mesa at its western end. Wrights Point is an excellent example of inverted topography. During late Pliocene time, a succession of fluid lavas followed an ancient, winding stream valley eventually filling in the canyon and hardening. As erosion took place, the softer rocks and soils of the adjacent valley walls were eroded away, leaving the streambed cast in lava projecting above the surrounding plain. Fossilized fish bones and freshwater clams and snails found in the strata below the lava of Wrights Point are evidence of the stream environment.

Smith Rock

Smith Rock State Park, seven miles northeast of Redmond, is nationally renowned by rock climbers. The name for the park goes back to early Oregon history. In 1863, soldiers, in pursuit of local Indians, were camped near Smith Rock when one of the men named Smith climbed to the top of the monolith to get a better view. Unfortunately the boulder on which he was standing rolled out from under his feet.

On the very northwestern edge of the Lava Plains province at Smith Rock State Park successive colorful tuffs in the canyon of the Crooked River have been eroded to create the fantastic rock shapes visible in the cliffs. In the park, the river winds its way past massive, towering rock walls, picturesque pinnacles, crags, and great slabs of upright rocks. Smith Rock, one of these vertical pillars, is part of a volcanic center which erupted 18 to 10 million years ago. Included with Smith Rock are Gray Butte, Coyote Butte, Skull Hollow, and Sherwood Canyon, all of which are part of a larger Gray Butte complex of volcanoes. Rhyolitic lavas, emerging from vents near the Crooked River, marked the beginning of the Gray Butte events. Falling ash expelled from the volcanoes covered the region to be followed by mud flows and more volcanic debris ejected during subsequent eruptions. The land surface

Wright's Point, a sinuous 250-foot high ridge in Harney County, traces the channel of a meandering stream that was permanently cast in basalt.



was repeatedly layered by this material. Once the volcanism subsided, the river slowly began to erode its way through the deposits to cut out the Crooked River canyon seen today. Fluvial erosion by the river over millions of years along with weathering of the rock have combined to carve the sheer walls of Smith Rock, which is formed of tan, red, and green tuffs of volcanic ash and mud flows.

The exact source of the volcanic material making up Smith Rock is uncertain. The eruptive center may have been a vent a short distance from the park, or Smith Rock itself may be the remnant of a low angle tuff cone. Lava from the cone exploded when it came into contact with groundwater and was expelled as ash that was later consolidated into tuffs.

Carved by the Crooked River into vertical pillars and sheer cliffs, the Miocene volcanic ash of Smith Rock is a favorite of rock climbers (photo courtesy of Oregon State Highway Department).

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