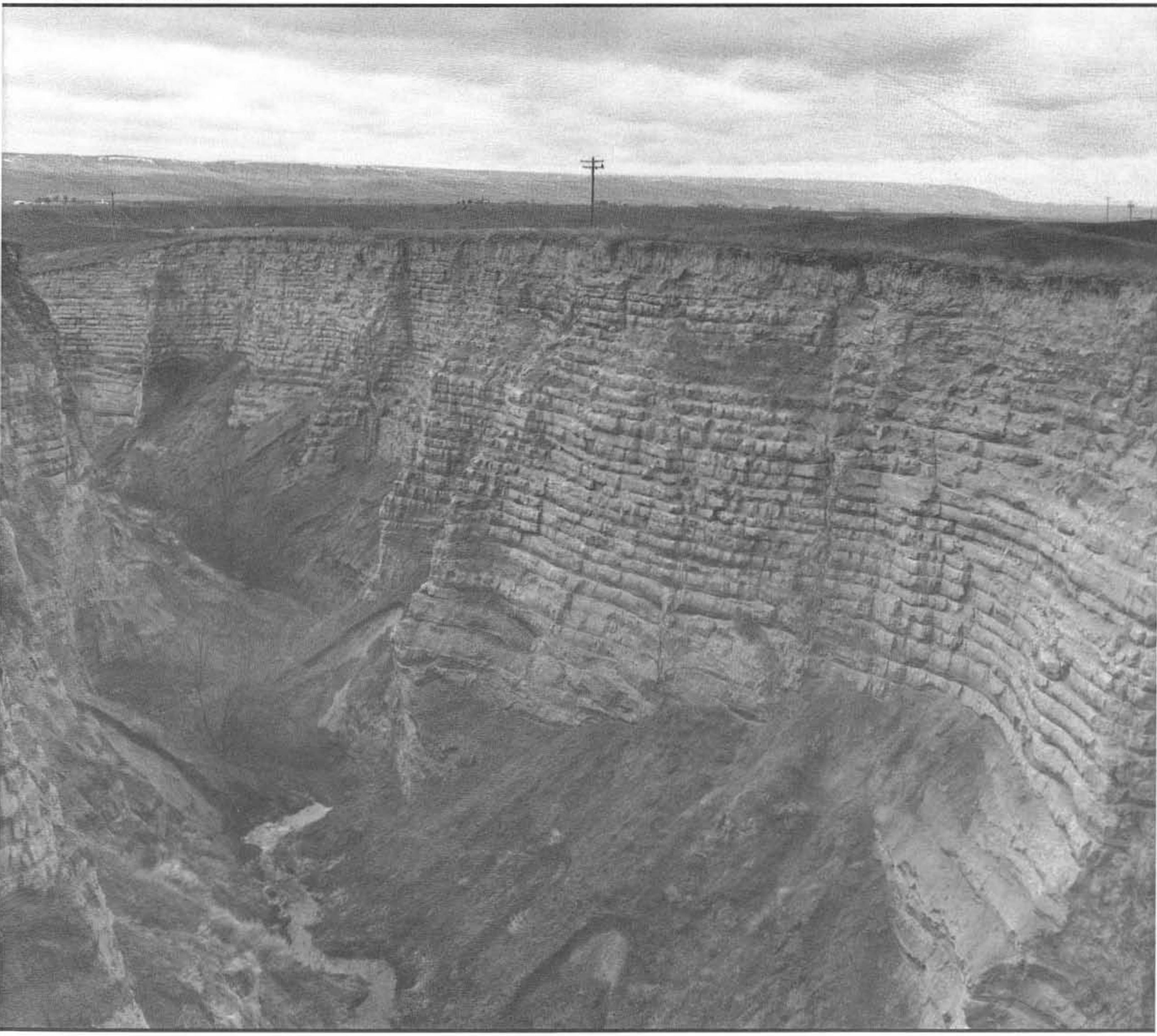
OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 56, NUMBER 1 JANUARY 1994



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OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 56, NUMBER 1 **JANUARY 1994**

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. If manuscript was prepared on common word-processing equipment (IBM compatible or Macintosh), a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, 3.5-inch high-density diskette only). Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover photo

Touchet (pronounced TOO-shee) beds at Burlingame Canyon near Touchet, Washington. The beds were exposed in 1926, when water escaping from an irrigation canal cut Burlingame Canyon. These layers settled out of turbid water during repeated inundations caused by catastrophic floods from Montana's ice-dammed glacial Lake Missoula. Article beginning on next page describes how Pleistocene floods and other catastrophic geologic events shaped the Pacific Northwest.

OIL AND GAS NEWS

Drilling at Mist Gas Field

Nahama and Weagant Energy Co., of Bakersfield, Calif., continues the multi-well drilling program at the Mist Gas Field in Columbia County. Of the first ten wells for the year, two have been completed as gas producers, three are suspended, four have been plugged and abandoned, and one was redrilled and is suspended. An eleventh well, HNR 24–22–64 was drilled to a total depth of 2,553 ft and was plugged and abandoned. Next, the well Johnston 11–30–65 reached a total depth of 2,794 ft and was plugged and redrilled to a total depth of 2,811 ft and then plugged and abandoned. The final well of the year, the Libel 32–15–65, was drilled to 2,835 ft, plugged, and abandoned. This concluded the Nahama and Weagant program for 1993.

Carbon Energy continues drilling

Carbon Energy International of Kent, Washington, continues drilling operations in Coos County, Oregon. The first well drilled, Coos County Forest 7–1, reached a total depth of 3,993 ft and is currently suspended. Drilling operations have been concluded at the second well, WNS–Menasha 32–1, but no results have been released.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
498	Carbon Energy Intl. Menasha Timber 16–1 36-011-00028	SW¼ sec. 16 T. 26 N., R. 13 W. Coos County	Application; 2,650. □

Who will catch the rain?

Under this theme, the Governor's Watershed Enhancement Board will hold its 1984 conference on Thursday/Friday, January 27 and 28, 1984, at the Ashland Hills Inn in Ashland, Oregon.

The Board consists of representatives from state commissions and agencies for natural-resource, environmental, and agricultural concerns and from several federal agencies.

The program will include sessions all day Thursday and until noon Friday, addressing such topics as watershed management, cooperation and partnerships, environmental education, and examples of watershed restoration and improvement projects. A banquet on Thursday will feature Steve Amen of Oregon Public Broadcasting, the executive producer of the television program *Oregon Field Guide*.

Further information is available from Liz Kraiter, Conference Coordinator, Northwest Rendezvous, 11700 SW Ashwood Court, Tigard, OR 97223, phone (503) 590-4240. □

U.S. POSTAL SERVICE STATEMENT OF OWNERSHIP, MANAGEMENT, AND CIRCULATION

Publication title: OREGON GEOLOGY, no. 600040; filing date 9-29-93. Published bimonthly, 6 issues per year, annual subscription price $8. Address of publication office, publisher's business office, editor, and owner: 800 NE Oregon St., # 28, Portland, OR 97232. Publisher and owner: Oregon Department of Geology and Mineral Industries; editor: Klaus K.E. Neuendorf; managing editor: Beverly F. Vogt, Publications Manager. No bondholders. Circulation during last 12 months/of single issue, respectively: Net press run 3000/3000; paid circulation est. 200/200; mail subscription 1456/1421; total paid circulation 1656/1621; free distribution 345/388; total distribution 2001/2009; not distributed 999/991; return 0/0; total 3000/3000. I certify that the statements made by me above are correct and complete.

Beverly F. Vogt, Editor

Catastrophic events
created and continue to shape
the western edge of the North American continent.

Geologic catastrophes in the Pacific Northwest

by George W. Moore, Department of Geosciences, Oregon State University, Corvallis, Oregon 97331

The following article was prepared for the Convention Guidebook of the 1993 National Speleological Society Convention at Pendleton, Oregon, and is printed here with the permission of the publishers. — *eds.*

IN THE BEGINNING

Before the Cambrian Period, the time when most animal groups such as clams and trilobites acquired their hard shells and their remains began to document the fossil record, most of the Pacific Northwest did not yet exist.

The continent of North America has had a long geologic history, and indeed some of the world's oldest rocks crop out in Canada and Greenland. But before the Cambrian Period, North America was attached to Australia and Antarctica along its western side (Figure 1). Only later did the states of Oregon and Washington move in to occupy a continental rift that until then had been firmly closed.

The rifting, the first geologic catastrophe in a long series to affect the Pacific Northwest, started about 700 million years ago during the Precambrian. The tectonic plate bearing Australia and Antarctica (and also India and China on its far side) broke away and began a long swing through the ocean that with other later breakups brought us to the present world scene (Hoffman, 1991).

Continental crust is about 35 km (22 mi) thick, and an open vertical fissure with a new ocean in it did not form at the rift where Australia and Antarctica broke away from North America. The Earth is too weak for that. For more than 20 million years, each incremental expansion of the rift at the future position of Oregon and Washington was followed by massive crustal slides toward it from both sides. Therefore, no crack opened along the rift, but giant faults broke up a wide belt of the flanking terrain. When new oceanic crust finally did begin to form, belts of disrupted continental crust several hundred kilometers wide tapered toward it from each side.

The tapering former edge of North America is well preserved in Nevada, where richly fossiliferous rock layers from younger geologic periods blanket the new continental edge. In the Pacific Northwest, however, later catastrophic geologic events removed that original tapering continental margin and replaced it with alien continental blocks.

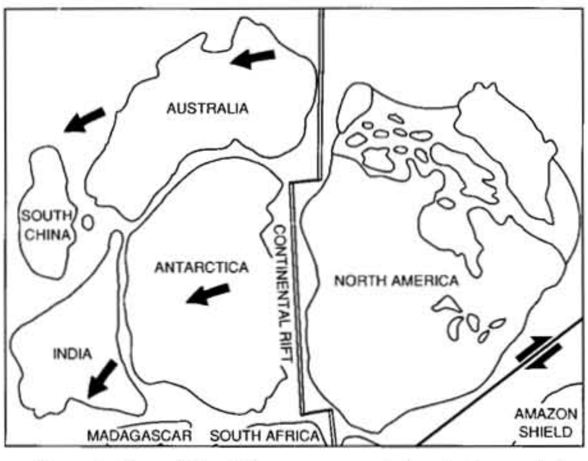

Figure 1. About 700 million years ago during the Precambrian, a continental rift separated North America from a much larger continent. Crustal stretching continued for 20 million years or more. Then a new ocean formed at the rift, and the Pacific Northwest established an anchorage on its North America margin.

GIANT BITES FROM THE CONTINENT

For a long period after the Precambrian breakup, the west coast of North America was tectonically quiet, and sediment banks and organic reefs built steadily seaward. Then, about 250 million years ago during the Triassic (some investigators say it was earlier), a disruption began, perhaps triggered by crustal stretching before the opening of the Atlantic Ocean and the consequent westward drift of the North America Plate (Howell and others, 1987). Sonomia, a large block of the Earth's crust now centered in western Nevada, was swept up and captured by the drifting continental plate of North America (Speed, 1983). This was followed about 200 million years ago, during the Jurassic, by the arrival of yet another big block, Stikinia, now centered in British Columbia (Figure 2).

These crustal blocks, which had formed as volcanic arcs and were plastered against the west side of North America, went a good way toward building the shoreline of North America out to roughly its present position. But after those blocks joined North America, giant bites were taken from the continental edge. In the first of these displacements, about 120 million years ago during the Cretaceous,

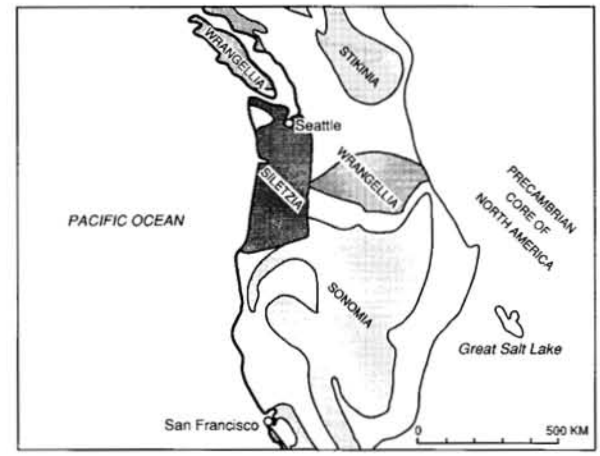

Figure 2. A succession of large blocks, mostly offshore volcanic arcs similar to today's Aleutian Islands, became attached to the Precambrian core of North America. First to arrive was Sonomia, then Stikinia. (Intervening onshore unpatterned areas are sea-floor materials squeezed between the blocks.) After Stikinia joined North America, it moved northward, reexposing the Precambrian core of the continent to the ocean. Into this gap came Wrangellia, the final great island-arc block. Then followed a series of displacements toward the north that separated Wrangellia into several fragments and left behind Siletzia, a tract of ocean floor. Later processes established the Cascade volcanic arc and understuffed and lifted up Siletzia to form the present Coast Range of the Pacific Northwest.

the previously captured Stikinia slipped toward the north, taking with it a part of Sonomia and much of the tapered continental margin of North America that had been left after Australia and Antarctica pulled away. In Idaho, this left a gap where oceanic crust of the Pacific Basin was juxtaposed against the Precambrian core of North America.

The nibbling of the continental edge was interrupted later during the Cretaceous by the arrival of Wrangellia (including the Blue Mountains of Oregon) into the gap at Idaho. Then a final great bite took place about 60 million years ago during the early Tertiary, when nearly all of what was then coastal Oregon and Washington was carried northward toward Alaska (Moore, 1984). This left behind Siletzia, the youngest tract of new ground in the Pacific Northwest.

Baja California of today may serve as a model for these dispersals of large tracts of land from Oregon and Washington. Baja California is moving northwestward along the San Andreas Fault, leaving behind new oceanic crust in the Gulf of California.

Siletzia is made of thin basaltic crust, and like the Gulf of California it, too, initially was a marine gulf underlain by new ground on the sea floor. Soon, however, a subduction zone was established along the margin of the Pacific Northwest, and the Cascade volcanic arc came into being. As part of the establishment of the new subduction zone, a wedge of buoyant sediment and rock was stuffed under the edge of Siletzia's new ground. The wedge lifted the edge of Siletzia above sea level, and today it forms the Coast Range of the Pacific Northwest.

But in eastern Oregon and Washington the land remained low; and sometime later, this interior lowland would become the site of yet another geologic catastrophe.

SWAMPED BY LAVA

About 17 million years ago, during the Miocene, fissures opened in eastern Oregon and Washington and began to deliver tens of thousands of cubic kilometers of basaltic lava to the land surface. Chemical analyses show that the basalt came from the Earth's mantle below the North America Plate. The repeated earlier disruption of the plate in this area may have played a role in the eruptions. Not known, however, is whether oblique crustal stretching related to movement of the San Andreas Fault was sufficient to trigger the lava outpourings (Hooper and Conrey, 1989), or whether a hot spot below the plate caused by large-scale overturn of mantle material was responsible (Duncan and Richards, 1991). The net result, however, was that the 3-km (2-mi)-thick Columbia River Basalt Group, representing one of the world's great flood-basalt provinces and consisting of over 300 individual lava flows, filled in the lowland of eastern Oregon and Washington (Figure 3).

Some individual lava flows ran all the way to the Pacific Ocean, protected from premature solidification by an insulating blanket of already hardened lava at the top of the flow. At the coast, the heavy lava entered the ocean through lava tubes and in places "floated" lighter sediment and sedimentary rocks to create a once-puzzling array of basaltic dikes and sills (Beeson and others, 1979).

Much of the scenic majesty of the Columbia River region owes its origin to these catastrophic outpourings of lava. Where the river has cut into them in the Columbia River Gorge, magnificent waterfalls punctuate the mighty cliffs that line the river.

THEN CAME THE DELUGE

The flood basalt of the Columbia River Basalt Group had long since solidified and begun to be deformed by younger Earth processes, when yet another great catastrophe hit the Pacific Northwest: stupendous floods of water that sculpted the Channeled Scablands in southeastern Washington. About 40 great floods, each containing roughly 2,000 km^3 (500 mi^3) of water and as much as 600 m (2,000 ft) deep, swept across approximately the same area as had been crossed by the basalt flows. They are the Earth's greatest known floods (Figure 4).

About 60 years ago, J Harlen Bretz, a professor of geology at the University of Chicago and the discoverer of the floods, first mapped and published the evidence for massive flooding in the State of Washington (Bretz, 1923). Thus began a long and difficult effort to convince the scientific community that the great floods indeed had occurred. Over the next 30 years, Bretz continued to map the area and to publish his evidence and conclusions, but acceptance of the concept was frustratingly slow. In the meantime, Bretz also did much other research, most notably his classic paper on the then also controversial topic that most limestone caves are formed below the water table (Bretz, 1942).

Part of the problem with Bretz' flood theory was that most people only read about it and never saw the evidence firsthand. Another part was that those who did investigate it were overly steeped in the doctrine of uniformitarianism (geologic processes have uniform intensity), which they interpreted to prohibit any form of geologic catastrophe.

Bretz' opponents were respected, and they were eloquent. Foremost among them was Richard Foster Flint, a former Bretz student (!) and a professor of geology at Yale University. Flint's major contribution was a paper in which he proposed that the Touchet beds, now recognized as the widespread deposits of the floods, were formed by uniformitarian processes of stream deposition beyond the front of an ice sheet during the ice age (Flint, 1938).

Year after teeth-gnashing year passed for J Harlen Bretz, but finally in the 1950s, aerial photographs became widely available. Suddenly, these revealed to everyone the fantastic patterns of giant ripple marks left by the floods (Bretz and others, 1956). Most of the ripples are difficult to recognize on the ground, but on the photographs they show up as giant water-laid dunes with heights measured in the tens of meters and wavelengths in the hundreds.

Bretz at first thought in terms of a single flood. We now know that this concept was derived from the evidence for the final molding of the ripples by the

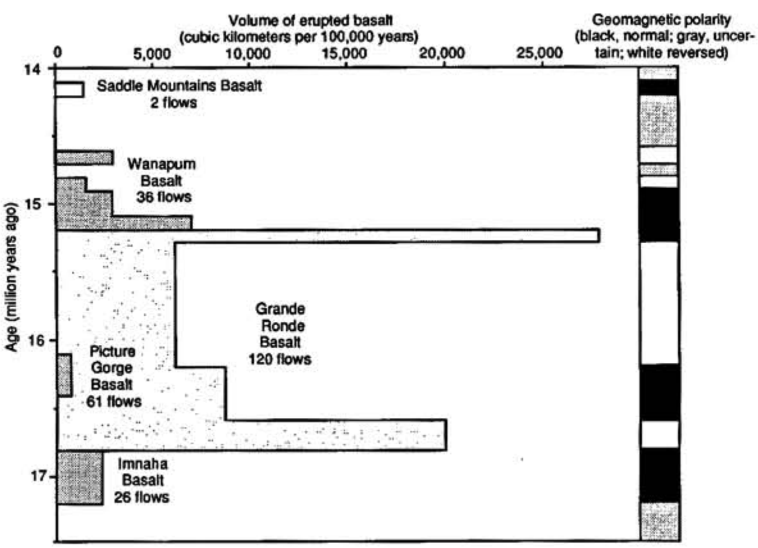

Figure 3. During a brief 3-million-year period, 170,000 km^3 (41,000 mi^3) of basalt flooded across the Pacific Northwest to produce the Columbia River Basalt Group. The over 300 flows in the formations of the group are identified by their structure, texture, and chemical composition, augmented by the magnetic polarity they recorded when the Earth's north and south magnetic poles repeatedly reversed. Abbreviated and simplified illustration based on data from Tolan and others (1989).

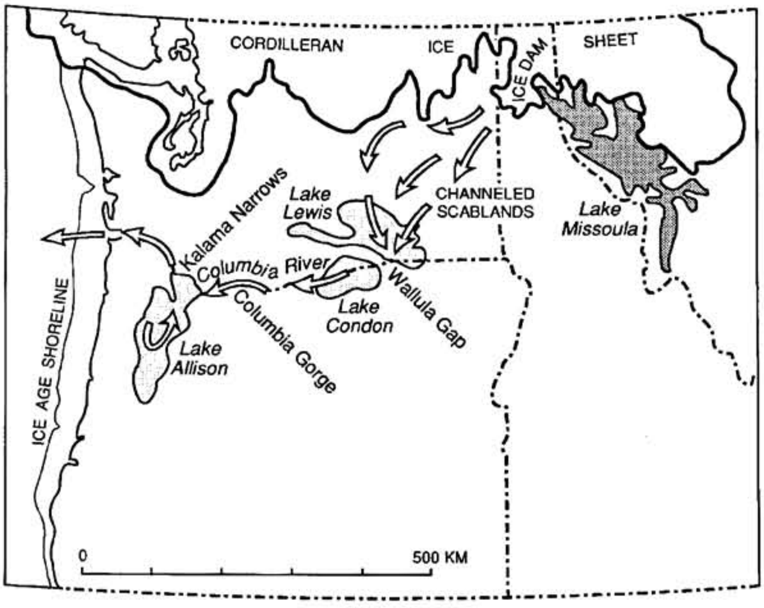

Figure 4. From 15,000 to 13,000 years ago during the ice age, a lobe of the Cordilleran Ice Sheet dammed Lake Missoula in Montana. When the lake reached a depth of 600 m (2,000 ft), its water floated the ice of the dam, flushing the lake water through the Pacific Northwest. Behind constrictions along the Columbia River valley, the water created giant temporary lakes. Where it rushed across high ground, it scoured out channels and laid down giant gravel ripples.

final flood in a long sequence. After later field work, he recognized that more than one flood had taken place, probably one for each major glacial stage. We now know, from the Touchet beds (cover photo) and other evidence, that 40 stupendous floods stripped off the surface of the Channeled Scablands and laid down the giant ripples and other deposits (Waitt, 1985).

The floods came from ancient Lake Missoula in Montana. A lobe of the Cordilleran Ice Sheet closed off the outlet to the lake with an ice dam. After a few decades with the dam in place, the lake filled, and when it reached a depth of about 600 m (2,000 ft), the water started to float the ice dam. Immediately, the dam burst, and the water of Lake Missoula swept down toward the state of Washington.

After each flood, the glacial lobe again moved slowly across the outlet, water filled the lake, the dam floated and burst, and the cycle was repeated—repeated 40 times. So, although they were catastrophic, these floods, recurring again and again over a period of 2,000 years, had a uniform intensity; hence they are, after all, an example of the doctrine of uniformitarianism.

ERUPTION PAST AND EARTHQUAKE FUTURE

Today, the Pacific Northwest has its own offshore tectonic plate, the Juan de Fuca Plate, and its own subduction zone (Figure 5). Subduction zones are notorious for two important types of geologic catastrophes: explosive volcanic eruptions and great earthquakes. The Pacific Northwest has had a long sequence of both.

The Juan de Fuca Plate moves eastward toward the coast and then curves downward and penetrates hundreds of kilometers into the lower mantle (Figure 6). At the same time, the North America Plate moves westward. One might think that the plates collide forcefully, but that is not so (Moore, 1992). The North America Plate overrides and pushes down the curve of the Juan de Fuca Plate and does not butt directly against it.

The lava of volcanic arcs above subduction zones differs from basalt delivered directly from the Earth's mantle in two important respects: it is lighter in color, and it is more viscous. Whereas highly fluid basaltic lava flows freely as a liquid—and makes the world's lava caves—the viscosity of subduction-zone lava causes it to push up into bulbous domes and then to explode violently. The most recent volcanic catastrophe of this sort in the Pacific Northwest was the eruption of Mount St. Helens in 1980.

About two months before the massive eruption May 18th at 8:32 a.m., which killed 57 people and devastated an area seven times the size of Manhattan Island, Mount St. Helens underwent several minor eruptions and began to swell measurably. The experts assumed that the activity would increase only gradually, and they laid out what then was considered a generous safety zone. But the swelling led to a bulge on the north side of the mountain, and on the day of the climactic eruption, the north side suddenly began to slide downward. The slip surface intersected the magma chamber within the mountain, and the unloading of the top abruptly released gas pressure inside.

The resulting explosion, similar to uncorking a champagne bottle, was wholly unexpected in size and force. Within seconds, a shock wave had turned a clear morning into deep overcast. A blast sped down the slope of the mountain at 330 km (200 mi) per hour, followed by a debris avalanche made of the former north side of the mountain and including giant blocks of glacial ice from the summit. An eruptive plume shot 16 km (10 mi) into the stratosphere and continued jetting steadily for the next nine hours. Mudflows of volcanic ash swept down the river valleys all the way to the Columbia River, 80 km (50 mi) away, disrupting river navigation for many months afterward.

The 1980 catastrophe at Mount St. Helens is the world's best studied volcanic eruption. We now know that magma depressurized and released by giant landslides has been common at other volcanoes elsewhere in the world, and the new knowledge will help to reduce the loss of life from such eruptions worldwide (Lipman and Mullineaux, 1981). But what about the other notorious natural hazard of a subduction zone? Should the Pacific Northwest expect a great earthquake in the future?

In historic time, Oregon and Washington have never had a great earthquake, that is, an earthquake larger than magnitude 7.5. And in Oregon even moderate-sized earthquakes are rare. This was long thought to be a good state of affairs, but we now know that a seismic gap of this sort is dangerous. The Pacific Northwest is waiting for a catastrophic earthquake.

American Indian tradition held that many lives were lost during a change in land level and the arrival of a great wave (now recognized as a tsunami) that took place not long before European fur traders arrived in the Pacific Northwest (Swan, 1870). Recent study on the basis of submerged coastal marshes and tree-ring dating shows, with an uncertainty of about 20 years, that this last great earthquake took place in 1680 (Atwater, 1987).

The experts know approximately when the last great earthquake occurred in the Pacific Northwest, but they are less certain about the interval between the great earthquakes. Intensive research continues on this topic, and several pre-1680 earthquakes have been identified. What remains uncertain is whether any preceding earthquakes were missed, because this is a critical ingredient in determining the recurrence interval and hence the probability of such an event soon. The best evidence now available points to a recurrence interval of 300 to 500 years. Hence, the Pacific Northwest should look for a great earthquake anytime from now to 200 years from now.

Future research may sharpen this estimate, and in the meantime building codes are being strengthened, and the public is being made

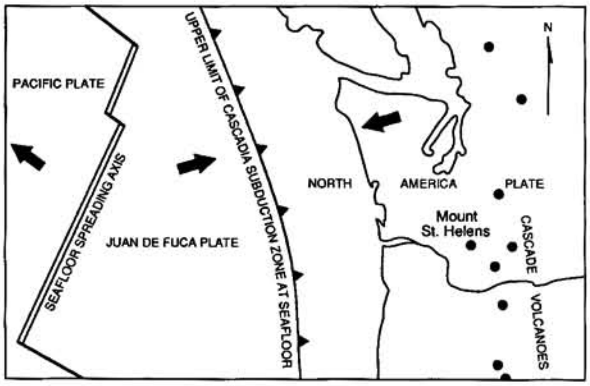

Figure 5. The Juan de Fuca Plate moves toward North America and bends down at the Cascadia subduction zone to produce the Cascade volcanoes and great subduction-zone earthquakes.

aware of steps that can be taken before, during, and after a great earthquake to reduce the danger.

The good news about subduction-zone earthquakes is that the fault slip surface is relatively far away, 50 to 100 km (30–60 mi) below the surface. This reduces the earthquake intensity. The bad news is that the slip zone is relatively long: in the worst case, all the way from British Columbia to northern California. This leads to a long period of shaking, up to four minutes, which can shake down buildings or send down landslides that might have survived briefer earthquakes.

Let's hope that all the right things are being done to thoroughly understand the next geologic catastrophe in the Pacific Northwest, so as to reduce its effects and make it a small one for us. As we have seen, it will join a long history of catastrophes, some of which were very large indeed.

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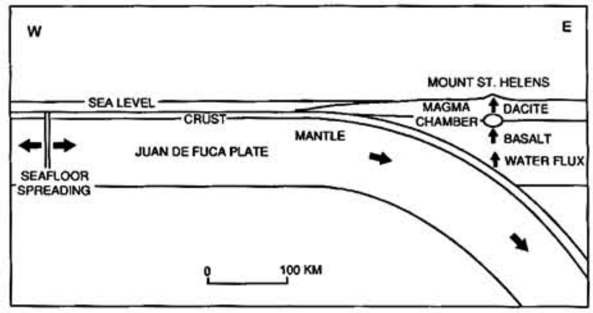

Figure 6. Cross section across the margin of the Pacific Northwest showing the downward bending of the Juan de Fuca Plate. Heat and water from the crust generate dark-colored basaltic magma in the overlying mantle, which in turn produces lighter colored magma below the volcanoes by the settling out of heavy, dark-colored minerals to change the composition of the remaining liquid.

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Oregon Academy of Science announces 1994 meeting

The Oregon Academy of Science will hold its fifty-second annual meeting on Saturday, February 26, 1994, at Oregon State University in Corvallis.

The meeting usually draws about 400 participants, including 100 at the Junior Academy level. It is an excellent chance to make contact with scientists at other Oregon colleges, universities, and research facilities. The meeting will have papers presented in sections of anthropology, biology, chemistry, economics, geography, geology, history and philosophy of science, mathematics, physics, political science, psychology, science education, and sociology. The Junior Academy will also have a full slate of papers.

This year's "keynote address" will feature *A Visual Triptych Of Science* with three 15-minute presentations aimed at the Junior Academy level but appropriate for all members. The presenters and the tentative titles of their presentations will be: Dr. Gordon Matzke (OSU Geoscience), "Should we invite a zebra to lunch?"; Dr. Patricia Muir (OSU Environmental Science), "The chemistry of fog"; and Dr. Phil Brownell (OSU Zoology), "Scorpions—up close and personal."

The conference registration fee of $10 includes a luncheon with the keynote program. Additional information is available from Dr. Dick Thies, College of Science, Oregon State University, Corvallis, OR 97331-4608, phone (503) 737-3879. □

Ground-water anomalies associated with the Klamath Basin earthquakes of September 20–24, 1993

by Paul J. Lienau and John W. Lund, Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon 97601
(An earlier version of this report was published in the *Geo-Heat Quarterly Bulletin*, v. 15, no. 2, November 1993, p. 17–19)

Two moderate earthquakes occurred approximately 30 km northwest (122.1°W. and 42.3°N.) of Klamath Falls, Oregon, on the evening of September 20, 1993 (Figure 1). These two were measured at magnitudes (M) 5.9 and 6.0 by the University of Washington and occurred at an approximate depth of 12 km. (The U.S. Geological Survey [USGS] National Earthquake Information Center in Golden, Colorado, reported preliminary magnitudes of 5.4 and 5.2 at depths of 10 km.) Numerous aftershocks measuring between M 2.8 and M 4.3, occurring in the same general vicinity, were felt in the area through September 24 (Figure 1). The earthquakes were felt in Salem (320 km north) and in Redding, California (200 km south). One person was killed by falling rocks on U.S. Highway 97, approximately 25 km north of town, and one person died of a heart attack, probably induced by the events. Unfortunately, there were no seismometers located in southern Oregon during the earthquakes; thus the data, recorded by more distant seismometers, are not as precise as is liked. Figure 2 is a seismogram of the 8:29 p.m. earthquake of September 20, recorded at Corvallis, Oregon, 285 km northwest of Klamath Falls. Since the earthquake, the USGS has established eight seismometers in the area to record aftershocks. They have recorded over 400 events of M 1.5 and greater since installation.

At least 300 structures were damaged by the quakes, several serious enough to be closed to public use. The most notable building severely damaged and closed to public use is the Klamath County Courthouse on Main Street in Klamath Falls. The Federal Emergency Management Agency (FEMA) has recommended that this structure be repaired, but it may take up to a year before the building can be occupied again. Buildings constructed of unreinforced masonry received the greatest damage, whereas buildings constructed of wood suffered little to no damage—typical of earthquake dam-

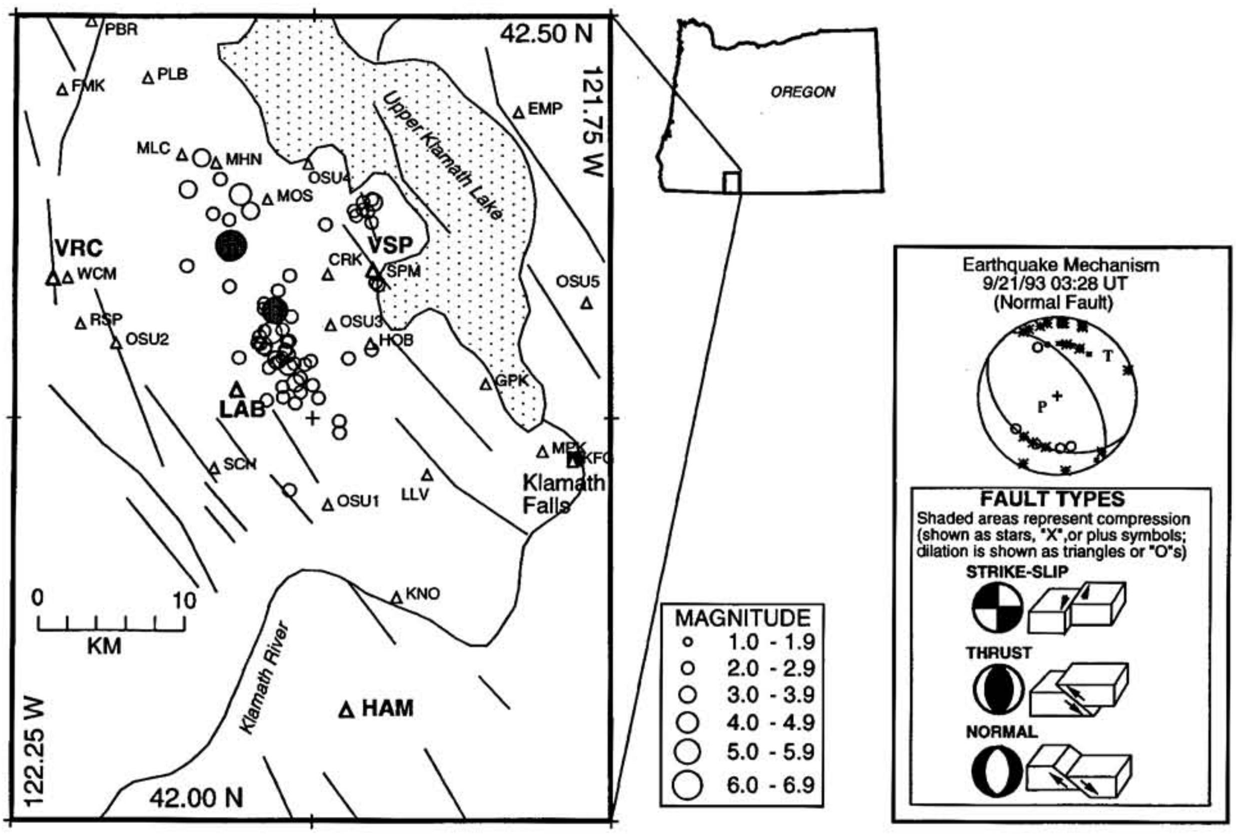

Figure 1. Plot showing best locations for earthquakes in the Klamath Falls, Oregon, area, third quarter of 1993. The two largest earthquakes (shaded circles) were on 9/21/93 at 03:28 (M = 5.9) and 04:45 (M = 6.0) UT. All locations contain arrival times from both CALNET (USGS, Menlo Park) and WRSN (UW, Seattle). Seismograph stations are shown as triangles. Most stations were portables deployed after the main shocks. Permanent stations VSP, VRC, LAB, and HAM (bold) were installed by the USGS in early October. Readings from portable stations are used for some aftershocks. Faults shown are from Pezzopane (1993). The normal focal mechanism (lower hemisphere, equal area) for the first main shock was determined from combined UW and CALNET polarities. The mechanism of the second main shock is similar. Computer image courtesy of Ruth Ludwin, University of Washington Geophysics Program.

age. Brick walls outside and inside buildings on the Oregon Institute of Technology (OIT) campus were also damaged, and some had to be closed temporarily. All are being used now, with some stairwells and entrances closed until the brickwork can be repaired. Throughout the city, no severe damage to utilities was found. Only minor leaks occurred in water lines and were quickly repaired. The total damage is at least several million dollars. It should be noted that none of the buildings in Klamath Falls meet the 1991 (adopted 1993) Uniform Building Code (UBC) earthquake zone 3 standards. Klamath County was originally in zone 1, then zone 2, and most recently in zone 2B according to UBC.

The Geo-Heat Center was especially interested in the effect of the earthquakes on the geothermal resource. In addition to measuring changes caused by the earthquakes, we also tried to document any precursor signals that may have occurred. These observations are discussed later in this paper.

Since 1945, at least 12 earthquakes have occurred within 33 km of Klamath Falls, but only seven of these were larger than M 3 (Jacobson, 1986). The largest recorded in this period was M 4.3 in 1948, and two of M 3.7 occurred in 1949. Based on the authors' personal conversations with local residents, minor building damage did occur in Klamath Falls from one or more of the 1948–49 earthquakes. Two earthquake swarms have also occurred within 150 km of Klamath Falls during the last 30 years: one in Warner Valley due east of Klamath Falls near Adel, Oregon (1968), and the other due south of the city at Stephens Pass near Mount Shasta, California (1978). The largest of these quakes was M 5.1.

The Klamath Basin is located at the western edge of the Basin and Range geologic province that extends eastward to Salt Lake City. The Klamath Basin, with the city of Klamath Falls located on its eastern edge, is a down-faulted graben. The horst blocks on either side have been estimated to have moved at least 500 m vertically. Several fresh fault scarps over 10 m high and several hundred meters long are visible in the basin. The absence of alluvial fans cutting across these fault scarps indicates that the faults have been active during the past several thousand years. These relatively young faults extend from Upper Klamath Lake southeastward to Tulelake, California, a distance of about 50 km, and probably extend northwestward to Crater Lake National Park (Figure 1). A study by the U.S. Bureau of Reclamation describes two recent fault zones along the west side of Upper Klamath Lake. One of these, the West Klamath Lake fault zone, has a fault scarp as high as 25 m cutting across glacial deposits less than 30,000 years old. Another scarp shows displacement of 1–2 m in deposits thought to be less than 10,000 years old. Geologists estimate that the West Klamath Lake fault zone is capable of generating earthquakes as large as magnitude 7.25. The September earthquakes appear to have originated in this fault zone.

Most of the original hot springs in the basin, the majority of which are located in the vicinity of Klamath Falls, are associated with the horst and graben structure. The geothermal utilization, mainly for space heating, is in the city of Klamath Falls. Approximately 500 wells tap geothermal fluids from 50°C to 110°C at depths from 30 to 600 m. The entire OIT campus, located at the northwest end of the well concentrations, uses 88°C geothermal water for space heating and domestic hot water (Lienau and others, 1989).

The September 20 earthquakes appeared to have had an effect on both the geothermal and cold-water aquifers in the Klamath Falls area. Long-term monitoring of both aquifers is done by well owners, the city of Klamath Falls, and the OIT Geo-Heat Center.

Well owners manually measure five residential wells daily for water level, using an electrical probe. After the earthquakes, all wells had water levels increase by 40–50 mm/day. Before the earthquakes, water levels were not changing. Generally, water-level increases in the hot-water well area have been 900 mm from September 15 to October 5. By comparison, during the same period in 1992 the water levels decreased by 208 mm, and in 1991 they increased by 18 mm.

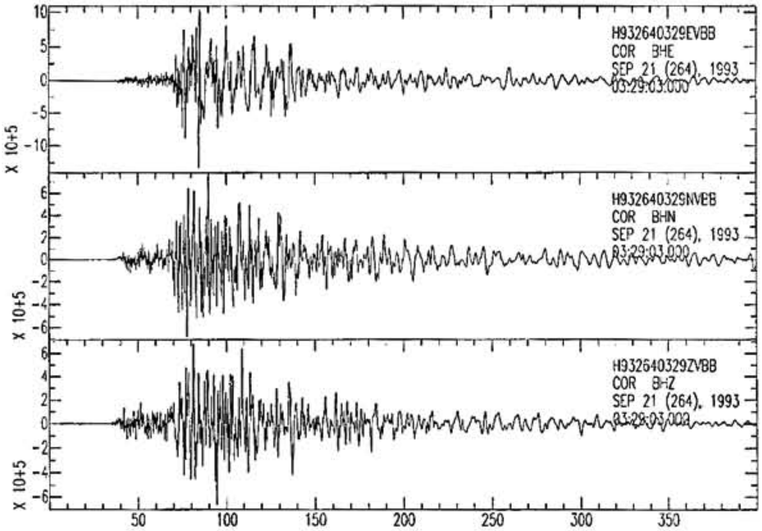

Figure 2. Three-component seismogram of the September 20, 1993, earthquake, recorded at Corvallis, Oregon, representing horizontal east-west (top), horizontal north-south (middle), and vertical (bottom) motions.

Long-term monitoring of five cold-water wells for water-level changes and bottom-hole temperatures is required by the Oregon Department of Environmental Quality for the permit to inject geothermal fluids at OIT. Shaft encoder water-level instruments and thermistors are connected to data loggers, which record on a 6-hour interval. Immediately after the earthquakes, water levels in all five wells decreased dramatically, about 0.3–2.1 m, depending on the well, for a duration of one to two days and then stabilized at the lower water level. Figure 3 is an example of a hydrograph showing the water level decline.

The city of Klamath Falls monitors a hot-water well at Laguna and Herbert Streets using a chart recorder that produces a continuous

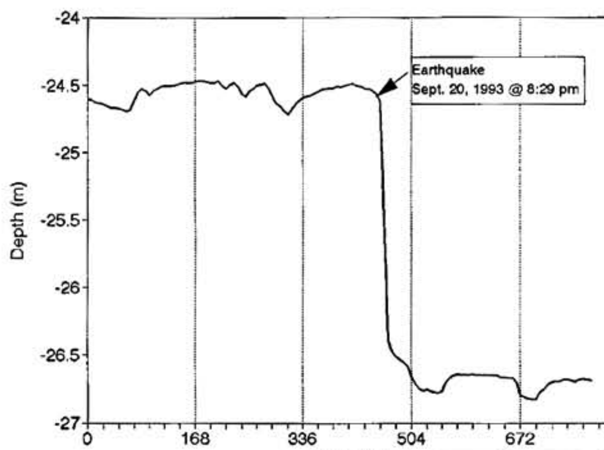

Figure 3. Hydrograph of motel observation well near OIT showing water-level decline as a result of the earthquakes. Data from September 1 to October 4, 1993; depth = 60 m, temperature = 13.5°C.

analog record of water level change. Prior to the earthquakes, there were very small changes in the water level. The earthquakes caused the cable to jump off the pulley, which was replaced on September 23. From September 23 to October 1, three aftershocks were recorded on the chart, and the water level increased about 150 mm from September 23 to September 24.

Ken Johnson, who manages Jackson Hot Springs in Ashland, Oregon, reported that the flow of the springs has increased by about 20 percent since the September 20 earthquake. The springs, which flow up to 100,000 gal/day, now allow him to fill his holding tank in about 43 hours instead of the previous 52 hours. The water temperature has not changed, remaining at between 86° and 96°F (Ken Johnson, personal communication, 1993).

Other hydrologic events that may be related to the earthquake include the following:

Klamath Medical Clinic geothermal well at 1905 Main Street started an artesian flow of approximately 115 liters per minute (L/min) about 1.5 months before the earthquakes. After the earthquakes, the flow increased to 570 L/min at 91°C (no apparent change in temperature).

A well behind City Hall used by Modoc Lumber Co. for makeup water to a boiler increased 5°C in temperature, from 18°C to 23°C after the earthquakes.

The Conger well field near Link River is used by the City as supply wells. After the earthquakes, these cold-water wells had an increase in water level of about 2.1 m.

Wells in an area about 25 km southeast of Klamath Falls in late July and early August 1993 reportedly began to smell and taste bad. In the same area, the Jim Moore well suddenly began producing 49°C water (estimated at 15°C before).

Finally, between 4:00 to 5:00 p.m. in the afternoon of September 20 (before the earthquake), water changed at the Gordon Aires well about 11 km south of the epicenter. The water was whitish gray in color with a tremendous amount of gas that had a strong "rotten egg" or hydrogen sulfide odor. Other well owners in the Keno area noticed similar changes to their wells. This area is southwest of the West Klamath Lake fault zone, along its structural trend.

Similar precursor changes in well water have been reported as far back as the sixth century B.C. in Greece. Springs in ancient Greece, in the Roman Empire, in Japan, and in China were reported to have become murky before a quake, with changes in taste and flow. Such changes were noted prior to the Haicheng, China, earthquake of 1975, when the entire city was evacuated just prior to a major earthquake. Approximately one month prior to this quake, well-water levels rose, hot springs stopped flowing, and some wells became muddy. Reports by the USGS indicated that earthquakes caused compression in some areas and tension in others, thus accounting for water-level changes after the events. Many cases of unusual behavior of animals prior to earthquakes have also been documented (Tributsch, 1982).

The March 27, 1964, Alaska earthquake caused significant changes in water levels in several artesian wells in the Anchorage area. In one, the water level initially dropped 4 m and then an additional 2 m. In others, the water levels within 5 days after the quake were 1–6 m lower. Wells in Palmer were also lower, and some in Chugiah were 1 m higher. The general rule was a lowering of the water level in artesian wells after the quake and a subsequent rise (Grantz and others, 1964; Waller, 1966).

According to Ferris and others (1962), "There will first be an abrupt increase in water pressure as the water assumes part of the imposed compressive stress, followed by an abrupt decrease in water pressure as the imposed stress is removed. In an attempt to adjust to the pressure changes, the water level in an artesian well first rises and then falls." This phenomenon has been noted in wells that are hundreds and even thousands of miles from epicenters. At these distances, the long-period waves of earthquakes cause the fluctuations; whereas in wells close to the epicenter, only the short-period waves can effectively move water rapidly into and out of wells (Thomas, 1940).

We are not sure about the meaning of the Klamath Basin events and whether or not some or all are related to the earthquakes. In any case, they are certainly out of the ordinary, based on about 20 years of monitoring the geothermal resource in the Klamath Falls area. We are continuing to monitor wells in the area and are also performing geochemical analyses of the water.

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Potentially new species of pond turtle discovered in Columbia River Gorge

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The deadly Pleistocene floods that buried Portland under nearly 400 ft of water, inundated the Willamette Valley as far south as Eugene, and scoured an area the size of the state of Delaware (approximately 2,000 mi^2) clean of all soil and vegetation may prove to be a creative force as well. (References to details of the floods from Allen and others, 1986).

Dan C. Holland, director of the Western Aquatic Turtle Research Consortium in Corvallis, believes the "Bretz floods" may have geographically isolated several rare populations of pond turtles found on the basalt ridges of the Columbia River Gorge. Holland believes the populations, which are currently classified as Western pond turtles, *Clemmys marmorata*, warrant listing as a new species (Holland, personal communication, 1993).

Holland, a herpetologist who has studied pond turtles in the west for more than 20 years, says the Gorge turtles are extremely difficult to tell apart from Western pond turtles, unless the animal is in hand. The forelimbs of older Western pond turtles are, for the most part, charcoal colored. The forelimbs of Gorge turtles bear charcoal scales tinged with pale yellow and thus have a slightly lighter appearance.

Just above the hind limbs, on folds of skin attached to the carapace (the upper shell), all these turtles bear a small scale called the "inguinal shield." In Gorge turtles, this is about half the size of the one found in Western pond turtles.

Less than 200 individuals of the potentially new species occur in a total of three locations in the Gorge. Two of the populations are in Washington; the third occurs in Oregon. In all cases, the pond turtles are found at elevations above the high-water mark postulated for the Bretz floods when they raced through the sections of the Gorge where the turtles occur.

"Bretz pond turtles" in the Columbia River Gorge differ visually from Western pond turtles in color and the construction of their shells.

J Harlen Bretz, the geologist for whom the catastrophic floods are named, first noted the erosive force of a massive Pleistocene flood in western Washington which he named the "Spokane flood" (Bretz, 1923). In subsequent papers, Bretz outlined how a series of cataclysms about 13,000 years ago carved the Channeled Scablands of Washington, fathered hundreds of hanging valleys and deserted plunge pools, and rafted hundreds of erratics (weighing up to 200 tons) as far south as Eugene.

Many geologists now believe that as many as 40 floods may have broken out from ancient Lake Missoula, a Pleistocene lake in western Montana formed (and reformed) when glacial ice repeatedly plugged the Clark Fork River. The 500 mi^3 of water that surged from the lake covered—at least in the largest of the floods—16,000 mi^2 of Montana, Idaho, Washington, and Oregon and stripped up to 150 ft of soil and loess from portions of the Columbia Plateau.

In the upper Columbia River Gorge, as John E. Allen puts it simply, "Anything under a thousand feet in elevation was wiped out" (personal communication, 1993).

Holland believes that the turtle populations high atop the basalt ridges of the Gorge may have narrowly escaped the floods, which in some areas brought a 1,000-ft-high wall of water racing through the Gorge. Sheltered and thus isolated, the turtles may have been genetically cut off from other populations by the disaster, says Holland. He notes that the nearest populations of Western pond turtles occur more than 60 mi away from the Gorge populations.

Holland, who received his doctorate in 1992 in environmental and evolutionary biology from the University of Southwestern Louisiana for his study of the relationship between geographic distance (and isolation) and morphological divergence in Western pond turtles, says he may propose naming the Gorge turtles after Bretz. Before the Gorge turtles would be accepted as a new species by the scientific community, Holland's findings would have to be published in a scientific journal and stand up to scientific scrutiny. Oregon's only other native turtle, the painted turtle (*Chrysemys picta belli*), shares a place on the Oregon state sensitive species list with the Western pond turtle.

Holland says that Bretz' work laid the foundation for his theory, which attempts to explain how Gorge turtles were differentiated from Western pond turtles in a process called "allopatric speciation"—the development of a new species through the geographic isolation of a population.

Isolation through geologic events is nothing new in natural history. Holland points out that the two species of Kaibab squirrels now present in the Grand Canyon (one species on the north rim, one on the south) are believed to have been derived from a single parent species. The gene pool of the squirrels, as the theory goes, was literally bisected in the ancient past by the downcutting of the Colorado River and the creation of the Grand Canyon.

Volcanism and orogeny, through time, have also acted as agents of geographic isolation, Holland notes.

The uniqueness of the geologic setting in the case of the Gorge turtles rests on the precision with which the event can be timed. "With the Columbia Gorge animals," Holland explains, "we have—hypothetically—a very recent event that we can determine with a high degree of accuracy. We not only know what physical event would have produced isolation, but we also know when it happened.

"When we look at patterns of differentiation in species," Holland continues, "it's rare that you can point out a specific geological event, and it's even rarer that you can point out the timing. This is one of the better documented cases we have."

Holland says that it was his reading of *Cataclysms on the Columbia* (Allen and others, 1986) that provided the hypothesis that led him to his theory about the isolation of the "Bretz" turtles.

To determine the extent to which the Gorge turtles vary from other pond turtle populations, Holland used a technique called "discriminate function analysis," a statistical system of calculating how far certain sets of variables deviate from other sets. By measuring variables (such as the size of the inguinal shield) not related to differences in sex or age, Holland came up with 13 variables in the Gorge turtles that, he says, set them distinctly apart from Western pond turtles.

"No matter how I did the calculations, the Gorge turtles always came up different," Holland explains.

If Charles Darwin had known about the Bretz turtles, perhaps his principal fears in publishing *The Origin of Species* would have been put to rest. Darwin noted in his 1859 text that the absence of intermediary links between species, in the geological record, formed a strong argument against the theory of evolution. (Darwin citations from Darwin, 1958).

Darwin stated that the record, due to its "extreme imperfection," failed to preserve evolutionary links between parent species and more recently evolved species. "Geology assuredly does not reveal any such finely graduated organic chain," Darwin said. "And this perhaps, is the most obvious and serious objection which can be urged against the theory."

Darwin noted that the principal of competition made quick work of parent species. "In all cases, the new and improved forms of life tend to supplant the old and unimproved forms."

But then Darwin never met the Bretz pond turtle. The Gorge turtles may, at the minimum, be considered intermediary forms, but their presence in the geologic record is illustrated in print, not in the strata. The "Bretz" turtle—if eventually classified as a distinct species—may be seen as an extremely rare, close link to a still-existing parent species, an animal that perhaps would have relieved Darwin of his principal worry.

Darwin would have appreciated the irony: the catastrophic Bretz floods providing a near-perfect geological record in regard to the isolation of the Gorge populations—and the floods themselves being the cause of the genetic isolation. "We continually forget how large the world is, compared with the area over which our geological formations have been carefully examined," Darwin noted, "we forget that groups of species may elsewhere have long existed."

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Inflated basaltic lava — examples of processes and landforms from central and southeast Oregon

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INTRODUCTION

Much of the land in central and southeast Oregon is relatively flat, notwithstanding extraordinary examples to the contrary. What processes are at work, and what landforms develop in basaltic lava that erupts onto these flat terrains? Fortunately, a number of young, accessible basalt flows offer relatively fresh, uneroded surfaces and landforms to study and enjoy. Road cuts, railroad cuts, and canyons offer cross-sectional views of the older, soil-covered lavas in these areas.

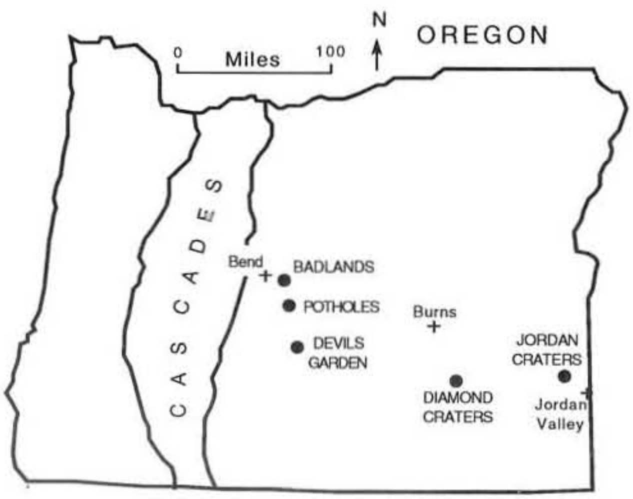

Figure 1. Location of basaltic lava fields discussed in this article.

Many of the youngest, highly fluid basaltic lava flows in central and southeast Oregon show distinctive forms and structures that have resulted from impressive swelling, or inflation (Chitwood, 1987, 1992, 1993a) (Figures 1-3). Beginning as thin flows only 20 or 30 cm (8–12 in.) thick, these lavas inflated in complex ways to thicknesses of generally 1.5–18 m (5–60 ft). Landscapes of low slope gradient, usually less than 2°, allow these pahoehoe lavas to spread out over wide areas and to develop elaborate tube-fed systems. Flow fronts, which initially advance rapidly, slow down as the lava fans out. Eventually, flow advance ceases when the strength and viscosity of a developing crust cannot be overcome by internal hydraulic pressures. But molten lava continues to flow into the system. The result is inflation. The surface crust rises, tilts, and cracks in complicated patterns.

Much of what is described and suggested in this article has been derived from observations of the remarkable landforms of basaltic lava fields around Bend, Oregon, and five basaltic lava fields of Quaternary age in central and southeast Oregon. The five fields include Badlands (Bergquist and others, 1990), Devils Garden (Keith and others,1988; Chitwood, 1990), Diamond Craters (Peterson and Groh, 1964; Brown, 1980), Jordan Craters (Calzia and others, 1988), and Potholes (Jensen, 1988) (Figure 4, Tables 1 and 2).

The term "inflated lava" was coined in 1972 by Robin Holcomb (personal communication, 1993) to describe fields of tube-fed pahoehoe lava that had swelled at Kilauea Volcano, Hawaii. He later included inflated lava in a morphologic classification of lava flows at Kilauea (Holcomb, 1987). Only in the past few years has detailed and exciting work begun on inflated lavas. Indeed, the term is only now becoming known among geologists and volcanologists. Geologic units described as "inflated lava" are appearing in increasing numbers on geologic maps (e.g., Kuntz and others, 1988). Inflated lava has been observed along the spreading center of the Juan de Fuca Ridge off the coast of Oregon (Appelgate and Embley, 1992). Many of the lavas of the Columbia River Basalt Group may be inflated (Hon and Kauahikaua, 1991; Self and others, 1991; Finnemore and others, 1993).

EVIDENCE FOR INFLATION

In the young basaltic lava fields of central and southeast Oregon, tilted slabs and surfaces of pahoehoe lava are common. The ropy or smooth surfaces of these slabs suggest they formed in essentially horizontal positions. The slabs usually make up the sides of raised areas of lava. Clefts or big cracks far too large to be accounted for by contraction during cooling often accompany tilted slabs. The tilted slabs, clefts, and raised areas suggest swelling from within the lava.

On lavas recently erupted from Kilauea Volcano, Hawaii, measurements of the surfaces of numerous tumuli show that swelling from within broke and tilted the overlying crust. When the tilted slabs are graphically made horizontal, the crustal pieces fit nicely back together (Walker, 1991).

Holcomb (1981, p. 94) describes evidence for inflation of lava during the eruption of Mauna Ulu on Hawaii: "The site is near the south wall of Makaopuhi pit crater, where a large boulder had fallen

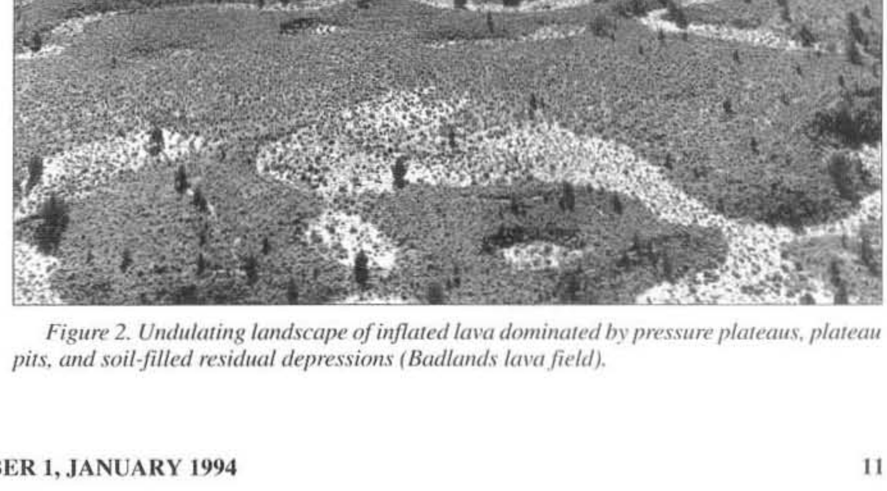

Figure 2. Undulating landscape of inflated lava dominated by pressure plateaus, plateau pits, and soil-filled residual depressions (Badlands lava field).

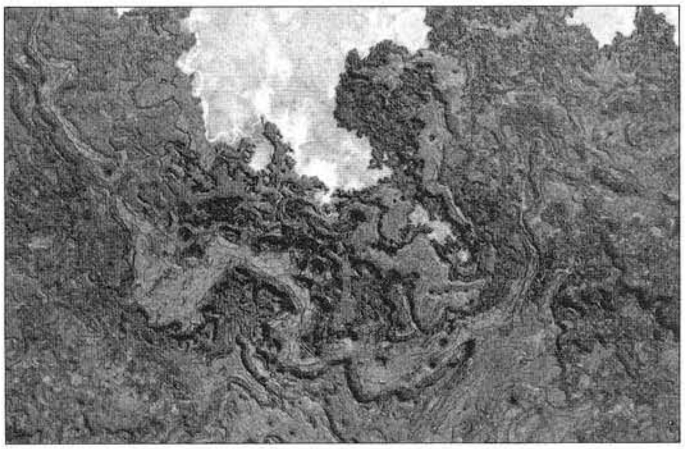

Figure 3. Air photograph showing several inflated flow units and features (5 mi northwest of Upper Cow Lake, Jordan Craters lava field).

onto the mezzanine. A small tree had grown from the top of the boulder. When the initially thin pahoehoe flow flooded the area, it chilled against the boulder, and where it was chilled it could not inflate. Inflation of the rest of the flow caused it to thicken about 4 m (13 ft), leaving the boulder in the center of a depression. The walls of the pit have an accordionlike structure that developed at the site of greatest differential expansion."

On the Mauna Loa lava flow of 1859, north of the Kona Airport in Hawaii, light-colored, angular rocks 8–25 cm (3–10 in.) across litter the surface in some areas. But you cannot pick up the rocks. The lower part of each rock is encased by and firmly held in the pahoehoe lava. They achieved their present situation when the first, thin flows surrounded them as they lay loose on the old, pre-1859 surface and encased them in a thin crust. Subsequent inflation of the flow carried these rocks vertically upwards 1.5–3 m (5–10 ft).

Lavas from the Puu Oo eruptions of Kilauea Volcano in Hawaii, which began in 1983, have encircled metal fence posts, cars, traffic signs, parts of incinerated homes, trees, and coconuts and carried them aloft 1.5–9 m (5–30 ft) as the lava inflated.

Lava flows have been observed and measured while inflating, but the rate of inflation is so slow that actual movement is seldom seen (Hon and Kauahikaua, 1991).

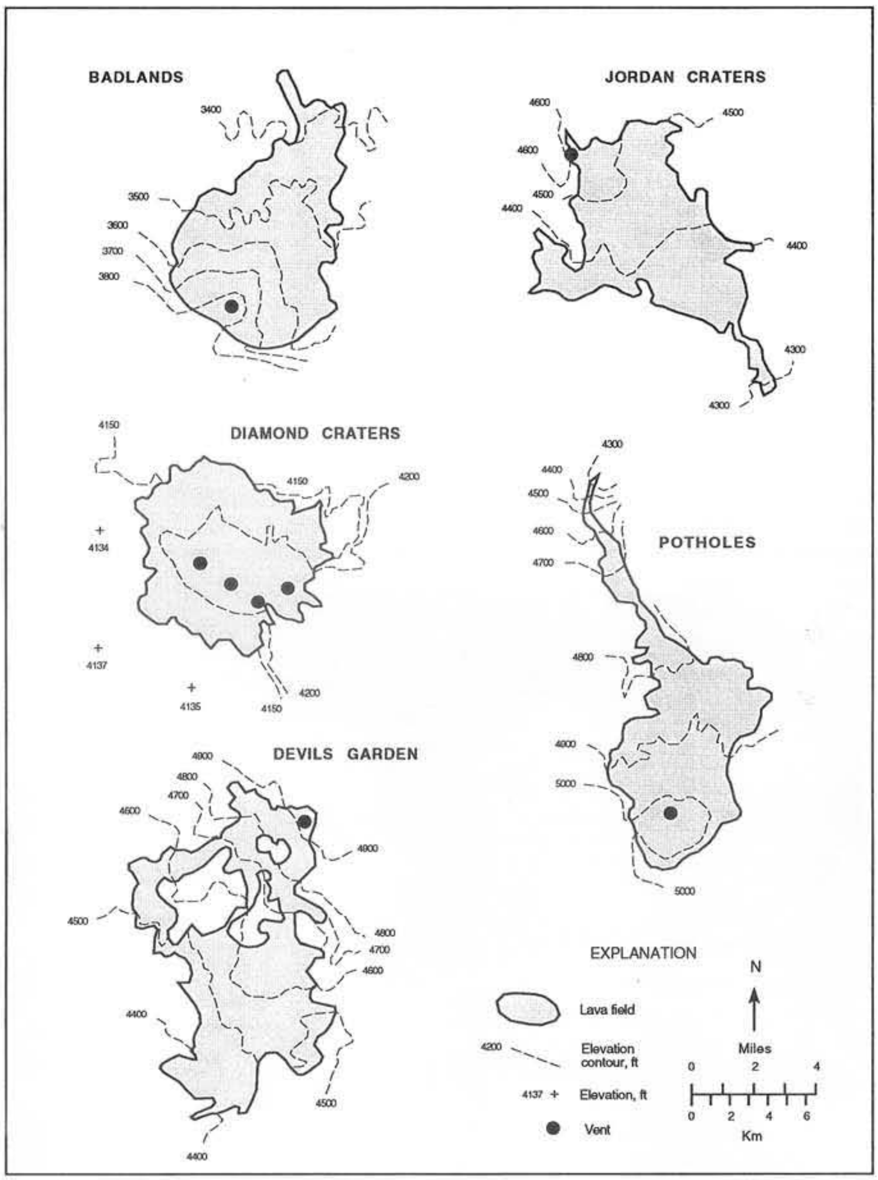

Figure 4. Overview maps of lava fields discussed in this article. Note low slope gradients in each field.

RHEOLOGICAL AND MECHANICAL BEHAVIOR

The ability of basaltic lava to inflate without rupturing depends on its rheological properties (i.e., properties pertaining to deformation and flow) at sub-liquidus temperatures. Above the liquidus, lava behaves essentially as a viscous (Newtonian) liquid. But below the liquidus, the rheologic properties are dependent on time and motion (Murase and McBirney, 1973; Hulme, 1974; McBirney, 1984; Dragoni and others, 1986; Solomatov and Stevenson, 1991). That is, lava held at a fixed, sub-liquidus temperature will have different viscosities and different yield strengths depending on how long the lava is held at the fixed temperature and how vigorously the lava is stirred. Viscosity and yield strength can increase greatly with time and with lack of stirring. Apparently, networks of atoms, molecules, and crystals grow and interact if allowed time and little disturbance.

For convenience, although vastly oversimplified, lava between the liquidus and solidus temperatures is in a zone here called the "zone of crystallization." For a slowly cooling lava lake of tholeiitic basalt in Hawaii, the zone of crystallization occurred between a liquidus temperature (100 percent liquid) of 1,210°C (2,120°F) and solidus temperature (95 percent solids) of about 980°C (1,706°F) (Wright and Okamura, 1977).

The potential for lava to inflate depends on the development of a tough, plastic region of high viscosity and yield strength that encloses lobes and sheets of lava (Figure 5). This plastic region thickens as molten lava cools conductively from its surface inward. The plastic region is within the middle of the thicker, migrating zone of crystallization within the lava flow. As the lava loses heat, the zone of crystallization thickens and moves inward at a rate approximately proportional to the inverse of time squared. The zone of crystallization con-

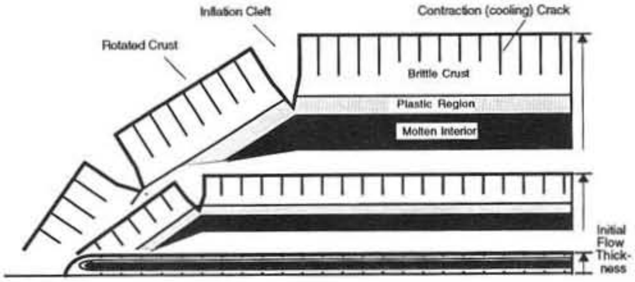

Figure 5. Cross-sectional diagram of inflating lava. A tough, plastic region surrounds the molten region and limits leakage and breakouts. During inflation, all zones thicken, contraction cracks lengthen, brittle crust tilts, and clefts open.

tains a wide range of crystal-to-melt proportions.

The rheological and mechanical properties at different places and times in the zone of crystallization will be strikingly different (Figure 6). The hotter, inner part of the zone contains few crystals and behaves essentially as a viscous liquid. This region has little or no yield strength, as evidenced by the rise of gas bubbles where lava has ponded. In the lava lake studied by Wright and Okamura (1977), bubbles ceased to rise when 55 percent crystals had formed at a temperature of 1,070°C (1,870°F).

The middle part of the zone of crystallization, the plastic region, contains a substantial percentage of crystals and behaves as a plastic with high viscosity and high yield strength. This material holds its shape until a sufficiently large force overcomes its yield strength, and the material begins to slowly bend, stretch, or flow.

The cooler, outer part of the zone of crystallization contains a high percentage of crystals, behaves as a brittle solid, and forms a crust over the plastic region. It fractures during cooling when tensional stress from contraction exceeds tensile strength. Blocks and columns of this brittle crust, which result from the fracturing, interlock to some degree and may support modest tensional forces.

DISTRIBUTION AND INFLATION

Fields of inflated lava are highly complex, hydrodynamic systems consisting of large numbers of flow units, most of which have inflated. An inflated flow unit is a region that has swollen or inflated to many times its original thickness. It possesses a relatively independent static or dynamic pressure regime and often develops from the breakouts or leaks of other flow units. Systems of inflated flow units spread out alongside, over the top of, and downslope from older systems.

Where lava pours from a breakout along a lava tube or an inflated feature, it floods an area by flowing and spreading rapidly. As it fans out, the velocity of the flow front decreases, and advance by flooding changes to advance by budding. Budding describes a process where small tongues or toes of red, rounded lava 10–20 cm or so (4–8 in.) in diameter break out, or "bud," from a crusted flow front (Figure 7). A toe emerges with a plastic skin that stretches as the toe elongates. A crust quickly develops and thickens, forming a rigid shell, and the toe ceases to advance. But increasing hydraulic pressure within causes a weak spot to distend and rupture, and another toe develops. The rate of advance by budding is quite slow, often on the order of 3–30 m (10–100 ft) per hour.

Flow units advance and inflate in at least two general styles: continuous and discontinuous. A continuous series of processes characterizes the continuous style of advance (Jackson and others, 1987). In the continuous style, the flow advances by budding (Figure 8). Toes and small lobes of lava branch and advance in all directions, while initially creating numerous, temporary kipukas (islands surrounded by other lava). The toes and small lobes run into and alongside each other, fuse, and coalesce. Lava passes through this

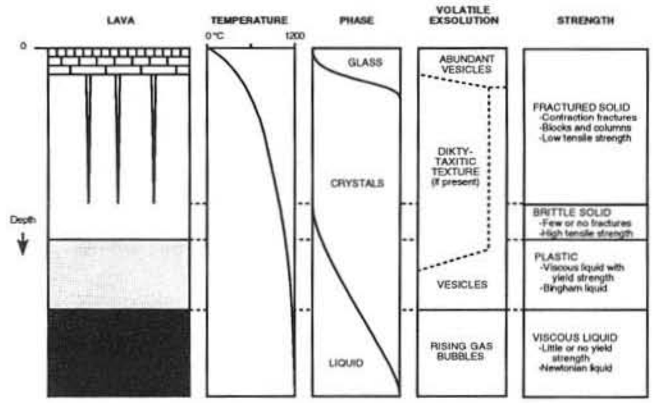

Figure 6. Physical properties of inflating basaltic lava. The zone of crystallization (where liquid changes to crystals) descends and thickens as heat is lost from the surface. Properties at different places and times within this zone will be strikingly different.

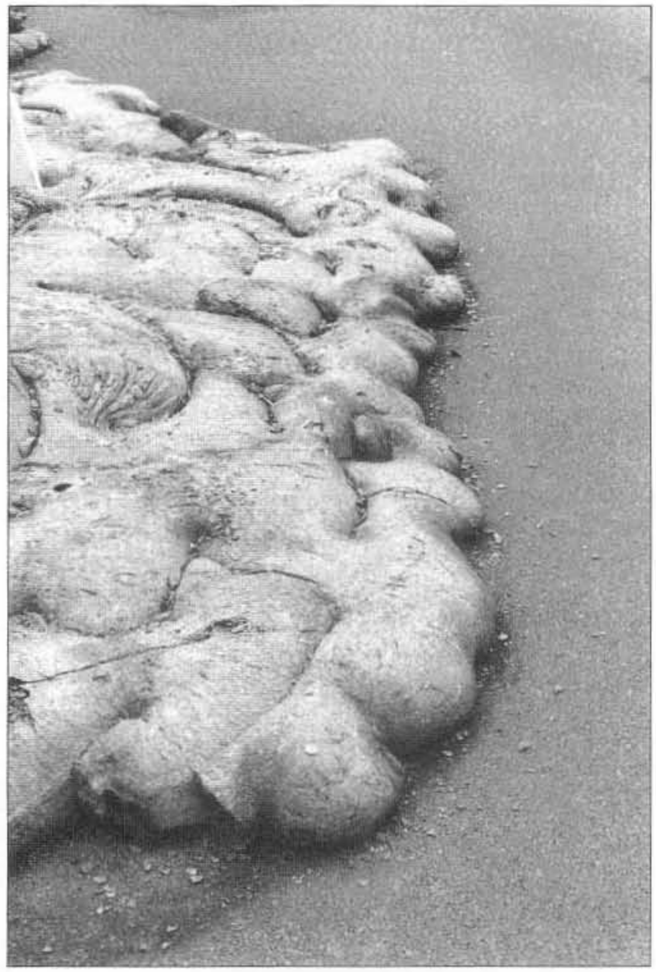

Figure 7. This 1990 lava flow in Hawaii advanced by budding as it flowed across Road 130, 1.5 km (1 mi) west of Kalapana townsite. Out of view to the left, the lava inflated to 30 times the thickness of these buds. Note penny on closest bud for scale.

interconnected maze, until the rigid septa (thin walls) between lobes become plastic by reheating. Hydraulic pressure then lifts a thickening crust upward. The septa pull apart as the flow inflates, and the interior of the lava flow becomes a more or less continuous molten

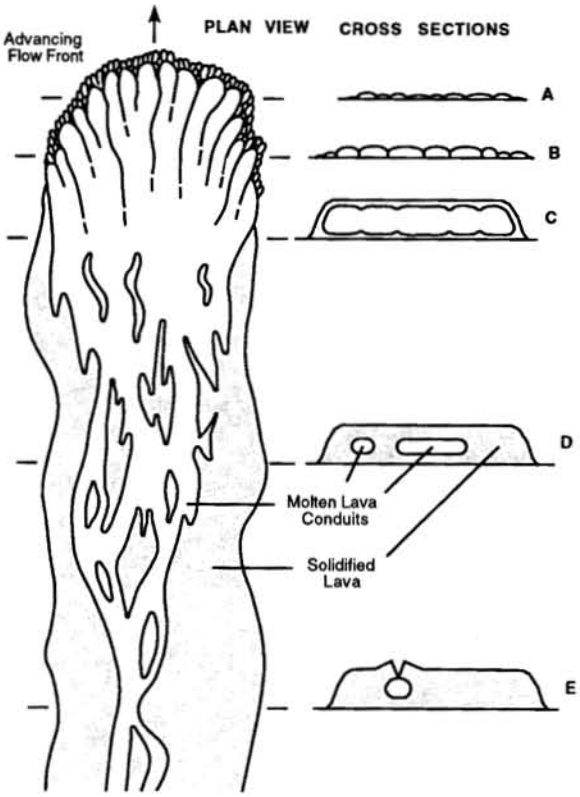

Figure 8. Continuous advance of an inflating flow unit. A. Flow front advances slowly by budding of pahoehoe toes. B. Septa between toes and lobes partially remelt; toes and lobes coalesce. C. Septa pull apart, and flow inflates. D. Slow-moving and stagnant regions solidify, while molten regions become confined to braided conduits. E. Molten lava confined to one or two conduits (lava tubes), which reinflate to create chain of tumuli and pressure ridges.

region. Later, this inflated region develops braided lava tubes. Eventually, as additional regions stagnate and freeze, only one or two lava tubes may remain active, which can reinflate to create a chain of tumuli and pressure ridges. A large area can be covered in such an inflated lava sheet, but in the field, unless the sheet is drilled, little evidence may exist to suggest that inflation has occurred.

In the discontinuous style of advance, an active flow unit spreads over a widening sector of land, advance eventually stops, the flow unit inflates and then develops one or more breakouts. Lava from the breakouts becomes the source for subsequent flow units. Breakouts seem to be sustained only when lava actively flows into an inflated flow unit and provides sufficient hydraulic pressure to maintain open cracks at breakout points. Inflated flow units can deflate catastrophically when a large breakout drains the unit before it gains structural integrity. Such drastic failures appear uncommon.

Routinely, the advancing lava develops inflated flow units that do not leak. Lava does not pass through them to feed downstream flow units but forms lava ponds perched on the land surface.

In Hawaii, large lava tubes that feed systems of inflated lava have been observed to fill and drain repeatedly. Measured elevations across the surface above these tubes show a corresponding and significant rise and fall (Kauahikaua and others, 1990). If a main tube remains drained for several tens of hours, the smaller branching tubes downstream become clogged with frozen lava. Refilling of the main tube may result in large breakouts from which new inflated systems develop.

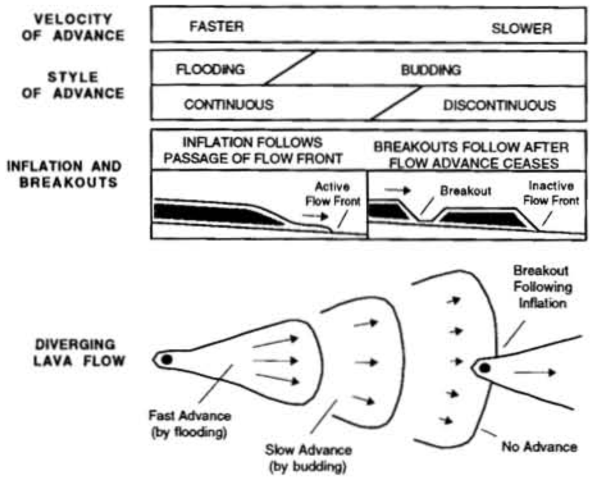

Figure 9. Styles of advance. Flow fronts advance continuously or discontinuously depending on velocity of advance.

The style of advance of a developing flow unit can change between continuous and discontinuous as topographic features influence the path and velocity of advance (Figure 9). Spreading of an active flow unit may be divergent, parallel, or convergent. If divergent, the velocity of the flow front decreases as it advances into a widening sector of land. The flow will tend to advance discontinuously. If parallel, the sides of the advancing flow unit remain roughly parallel, and the velocity and style of advance will tend to remain constant. If convergent, the velocity increases as the flow thickens and advances into a narrowing sector of land. The style of advance will tend to change from discontinuous to continuous. In fields of inflated lava, determining what style of advance occurred, what is or is not part of a flow unit, and how an inflated feature is connected to another is usually difficult and often impossible. However, places exist where these connections and the results of processes are well displayed.

Flow units that display a great range of widths can be traced routinely. Along its course, a single flow unit may consist of a web of one or more tumuli, pressure ridges, pressure plateaus, and narrow connecting channels. Notably, the narrower places are less inflated. Resistance to inflation in narrow regions is related in part to the radius of curvature of the conduit (lava tube). If the conduit is thought of as a pipe, then the tensile force that develops in the pipe wall is proportional to the radius of the pipe for a given hydraulic pressure. The yield strength of the plastic region in the conduit wall is often sufficiently high to reduce or prevent stretching.

Fields of inflated lava in central and southeast Oregon show a general organizing characteristic in which a wide, central, inflated flow unit that advanced in a continuous style is connected to and flanked on one or both sides by numerous inflated flow units that advanced discontinuously.

VESICLES AND FRACTURES

In vertical cross sections of inflated flow units, patterns of vesicles and fractures offer insight into processes once active (Figure 10). Inflated flow units display three vesicle zones (Aubele and others, 1988). In the upper vesicular zone, the abundance of vesicles decreases, and vesicle size increases, with depth. At the top of this zone, vesicles can account for more than half the volume of the rock. Within the middle nonvesicular zone, vesicles are rare (except for vesicle cylinders, vesicle sheets, and the microvesicles of diktytaxitic texture). In the lower vesicular zone, the trends of size and abundance are reversed compared to the upper zone. This zone is thinner than the upper zone, seldom exceeding 0.5 m (1.5 ft).

Table 1. *General descriptions of basaltic lava fields discussed in this article*

	(Units)	Badlands	Devils Garden	Diamond Craters	Jordan Craters	Potholes
Slope	(°)	0.8	0.6	0.5	0.9	0.5
Area	(km^2)	75	86	67	65	65
	(mi^2)	(29)	(33)	(26)	(25)	(25)
Volume	(km^3)	1.4	1.2	1.0	1.0	0.96
	(mi^3)	(0.34)	(0.31)	(0.24)	(0.24)	(0.23)
Thickness[1]	(m)	19	15	15	15	15
	(ft)	(62)	(50)	(50)	(50)	(50)
Age	(yr)	300,000[2]	20,000[2]	17,000[3]	3,200[4]	50,000[2]

[1] Estimated.

[2] Estimated age, this report. Hawkins and others (1989) report a K-Ar age of 700,000. However, the Bend pumice, approximately 370,000 yr old (Hill and Taylor, 1990), underlies Badlands lavas.

[3] Hydration rind age date (Friedman and Peterson, 1971, p. 1028).

[4] Radiocarbon age (Mehringer, 1987, p. 60).

Table 2. *Major element chemistry for basalts discussed in this article, in percent (FeO* = total Fe expressed as FeO)*

	Badlands[1]	Devils Garden[1]	Diamond Craters[1]	Jordan Craters[2]	Potholes[1]
SiO_2	50.36	48.88	47.74	47.45	49.28
Al_2O_3	17.29	16.51	17.62	16.15	17.17
FeO^*	8.65	9.47	9.82	10.45	9.27
MgO	8.45	9.49	8.61	9.09	8.72
MnO	0.15	0.17	0.17	0.17	0.17
CaO	9.6	9.77	11.53	9.77	10.17
Na_2O	3.41	3.31	2.86	3.07	3.09
K_2O	0.54	0.56	0.3	0.69	0.53
TiO_2	1.28	1.48	1.17	2.38	1.28
P_2O_5	0.25	0.36	0.17	0.27	0.32
Total	99.98	100.00	99.99	99.49	100.00

[1]This article, Run 1391, 28 Sep 91, Wash. State University. Elements normalized on a volatile-free basis.

[2] Hart and Mertzman, 1983, p. 16.

The upper vesicular zone develops as bubbles nucleate and rise in the flowing, molten lava. The bubbles accumulate under the thickening crust and become trapped at progressively greater depths (Figure 10a). The thickness of this zone is primarily controlled by the length of time that gas-saturated lava flows through the unit (Cashman and others, 1993). When the flow rate decreases, the rate of bubble production decreases. Changing flow rates and pressures modulate the rate and size of bubble production. These fluctuations in flow rate and pressure are recorded as layers poorly or richly endowed with vesicles. A flood of bubbles can accumulate and coalesce under the descending solidification front to form gas pockets and cavernous layers. An alternating sequence of bubble-poor and bubble-rich regions can impart a striking layered appearance to the upper vesicular zone (Figure 11). Similar-looking but unrelated cavernous layers may develop when the level of lava in a lava tube or inflated unit temporarily drops and a new, thin crust develops in the open space (K. Cashman, personal communication, 1993).

In the lower vesicular zone, most bubbles that nucleate here rise before becoming trapped in the upward-moving solidification front. Consequently, this zone is much thinner than the upper zone.

Diktytaxitic texture, vesicle cylinders, and vesicle sheets are the primary features of the middle nonvesicular zone. ("Nonvesicular" is apt only in the sense that few or no vesicles are visible when a rock outcrop is viewed from a distance of 1–2 m (3–6 ft).) Diktytaxitic texture often extends beyond the middle zone to within 30 cm (1 ft) or so of the top and bottom of the flow unit. This diktytaxitic texture pervades most inflated basaltic lava of late Tertiary and Quaternary age in central and southeast Oregon. Fuller (1931) first described and named diktytaxitic texture when he encountered it in the Steens Basalt in southeast Oregon. The texture is characterized by numerous jagged, irregular microvesicles bounded by crystals (mostly plagioclase), some of which protrude into the cavities.

The first episode of gas exsolution from the lava created the bubbles of the upper and lower vesicular zones. A second episode created diktytaxitic texture (Figure 10b). The microvesicles develop as dissolved gases concentrate in the liquid part of a cooling inflated flow unit. At a critical concentration, the pressure of exsolving volatiles exceeds the mechanical strength of a growing crystal network (Chitwood, 1993b). The gas pressure creates microvesicles by distorting, rearranging, and opening up the crystal network. The microvesicles interconnect to a large degree, and at the moment of interconnection, gases gain sudden access to the atmosphere through a vast network of previously formed and interconnected microvesicles. Interconnection aborts growth of the microvesicles. At the Badlands and Potholes lava fields, diktytaxitic texture accounts for approximately 10 percent of the volume within inflated flow units.

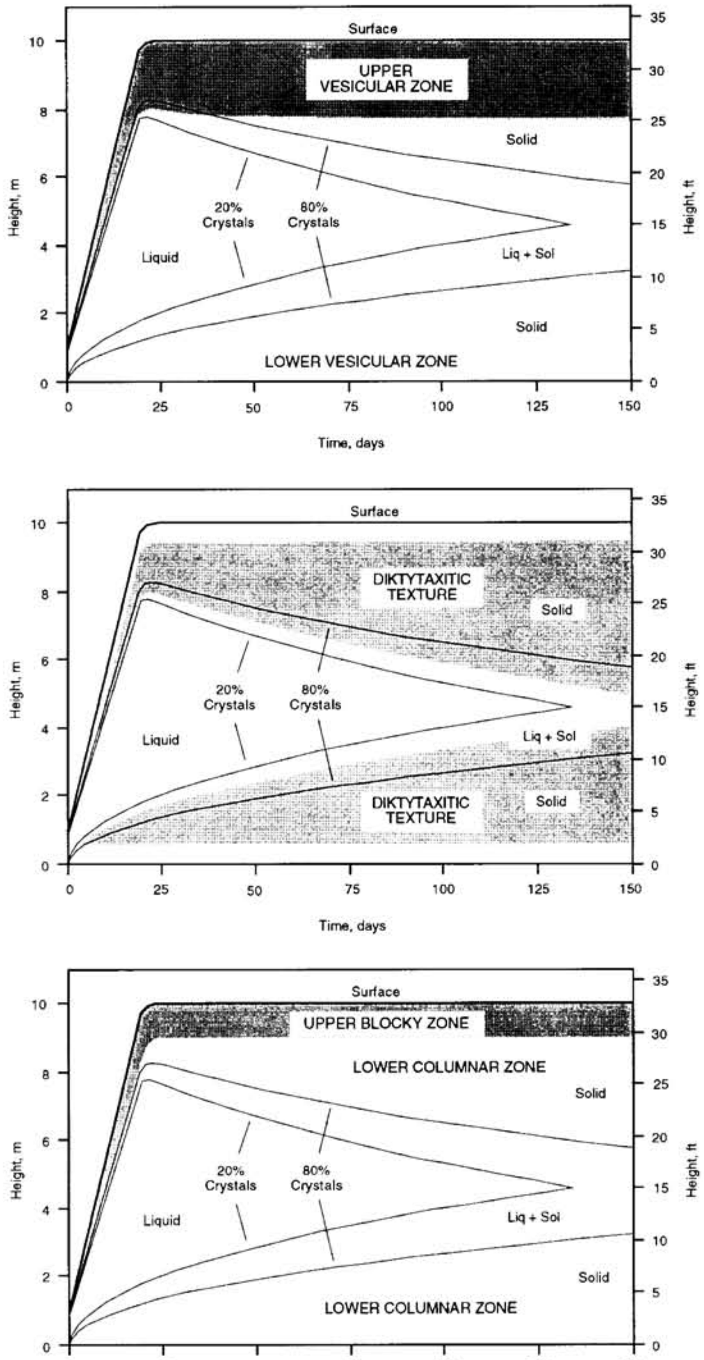

Figure 10. During cooling of a hypothetical inflated basaltic lava flow, gases exsolve, and fractures develop in patterns that depend largely on the mechanical properties at different places and times. 10a. Upper and lower vesicle zones grow only where gas-saturated lava contains less than approximately 50 percent crystals. 10b. Microvesicles of diktytaxitic texture nucleate and grow only where gas-saturated lava contains more than approximately 50 percent crystals. 10c. Cooling fractures develop following solidification. Initial rapid cooling produces closely spaced fractures; slower cooling produces more widely spaced fractures.

Diktytaxitic texture appears to predispose basaltic lava to cavernous and honeycomb weathering in central and southeast Oregon, especially where microvesicles are abundant (usually liftup caves and inflation clefts) (Figure 12). A crude relationship is apparent between age of lava and degree of cavernous weathering. For example, at the Jordan Craters lava field, weathering has removed up to 13 mm (0.5 in.) of lava in local areas, while at the Badlands lava field up to 1.2 m (4 ft) have been removed. Badlands lava is about 100 times older.

Fracture patterns develop in inflated lava from tensional stresses due to contraction during cooling (Aydin and DeGraff, 1988). Two fracture zones are notable (Figure 10c). The upper blocky zone consists of closely spaced fractures and short, stubby blocks and columns. These result from steep thermal gradients near the top of flow units that create strong, local stresses during and following solidification. These stresses may interact with vesicle-layered lava and produce striking platy and blocky layers.

In the lower columnar zone, distance between fractures increases where thermal gradients are less and stresses more widely distributed. Here, large, wide, crude columns develop that are often 1.5 m (5 ft) or so in diameter. The notably low strength of diktytaxitic lava may prevent the development of the well-organized, slender, prismatic columns characteristic of many flows of the Columbia River Basalt Group.

LANDFORMS AND STRUCTURES

Inflating lava develops distinctive morphologic features as well as an endless variety of hummocky and chaotic features not easily described (Figures 13 and 14).

The following are descriptions of distinctive and common landforms and structures found in fields of inflated lava. Many have been described previously (e.g., Wentworth and Macdonald, 1953), but their origin was poorly known. Several landforms described here have not been previously named. They include rotated crust, plateau pit, liftup cave, extrusion wall, and deflation lava cave.

Rotated crust is a coherent slab or block of lava crust that has been tilted or rotated. Crust tilts or rotates wherever inflation is greater in one area than in an adjacent area. Since the axis of rotation is not always horizontal or fixed, the term "rotated" describes the movement of the crust more accurately than "tilted."

An **inflation cleft** is an elongated crack or cleft on the surface of inflated lava and develops during bending and tilting of lava crust (Walker, 1991). The opposing walls of a cleft match up except low in the cleft, where widening and deepening takes place in the plastic region. At the bottom of the cleft, molten lava sometimes leaks or breaks out. Also, **squeeze-ups** of semi-rigid lava can be forced out in impressive wedges (Figure 15).

A **tumulus** is a circular or oval mound of inflated lava with rotated sides and usually a medial inflation cleft (Figure 16). Many tumuli have two or more inflation clefts. At others where no cleft forms, extension or spreading apart of the brittle surface during inflation is distributed among numerous small contraction fractures. A tumulus develops over part of an active, filled lava tube under enough pressure to force its roof upward. A highly elongated tumulus grades into a pressure ridge. Most tumuli are 1.5–6 m (5–20 ft) high, but Badlands Rock in the Badlands lava field is 30 m (100 ft) high.

A **pressure ridge** is a relatively narrow but long ridge of inflated lava with sides that have been uplifted and rotated outward. It forms above an active, overpressured lava tube. Usually, one or more inflation clefts develop lengthwise

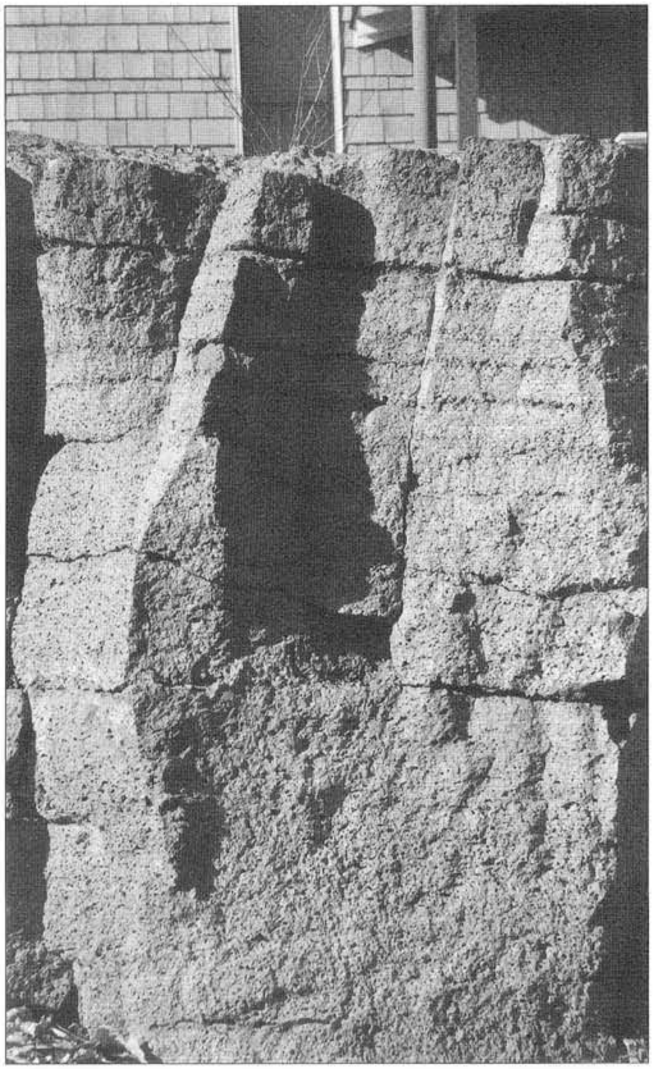

Figure 11. Changing pressure and alternating batches of gas-saturated and unsaturated lava created these vesicle-rich and vesicle-poor layers near downtown Bend, Oregon. Height of outcrop is 1.5 m (5 ft).

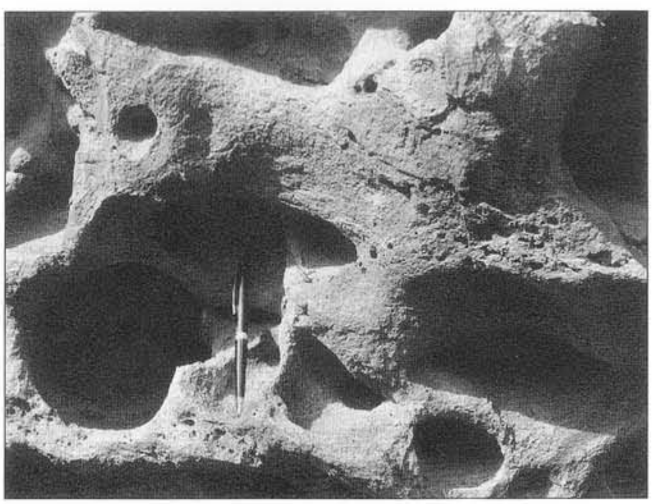

Figure 12. The presence of diktytaxitic texture may predispose inflated basaltic lava to cavernous and honeycomb weathering (The Castle, Badlands lava field).

Figure 13. This pahoehoe lava flow from Kilauea Volcano, Hawaii, inflated after burying part of Highway 130 (southwest of Kalapana townsite) in 1990. Initial flow lobes that crossed the road were thin, similar to the one at far left foreground. The morphology of inflated lava often appears hummocky and chaotic as seen here.

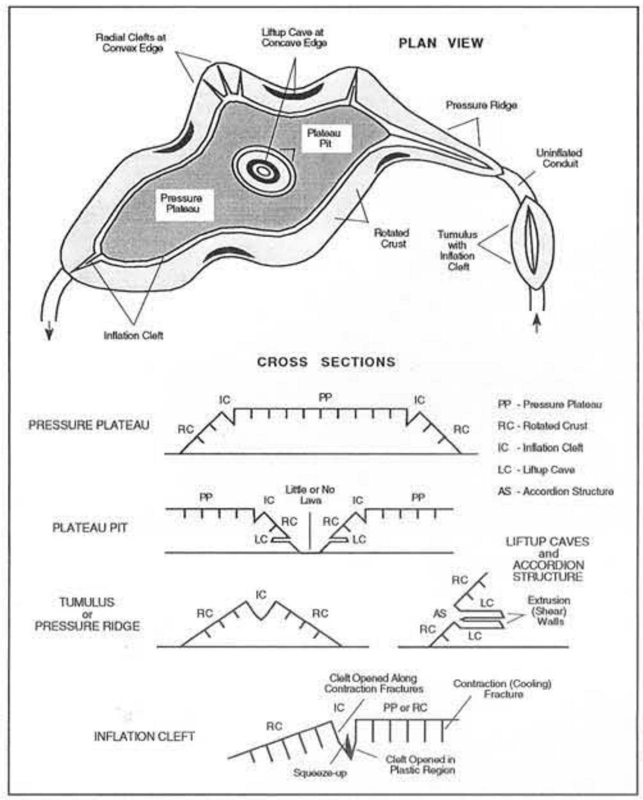

Figure 14. Generalized drawing and cross sections depicting common landforms and structures of inflated basaltic lava.

along its crest. (The term "pressure ridge" is also used to describe an elongate uplift of lava caused by a compressive crumpling of crust.)

A **pressure plateau** is a broad, extensive area of inflated lava that has a horizontal or subhorizontal, elevated surface and sides of rotated crust (Figures 17 and 18). Inflation clefts usually develop around the perimeter of, and sometimes in, the elevated surface and in the rotated crust. The flat, elevated surface represents hydrostatic equilibrium when the pressure plateau possessed a molten interior. A pressure plateau can extend laterally from several meters to more than 1.5 km (1 mi), and its thickness can range from 1 m to more than 21 m (3–70 ft).

A **residual depression** is any closed basin within a field of inflated lava that has sides of contemporaneous lava (Holcomb, 1987). These depressions are common and vary widely in size.

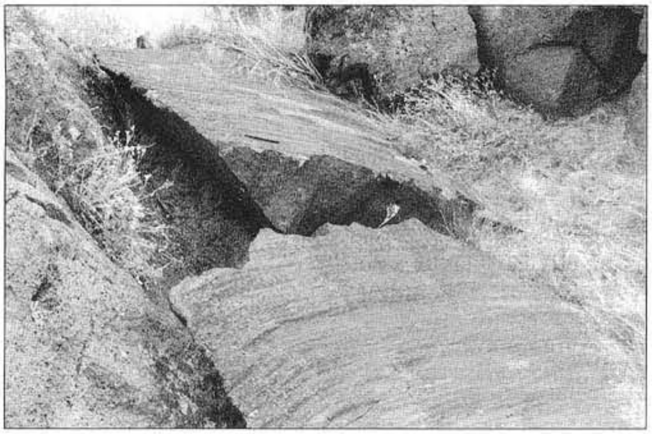

Figure 15. Example of squeeze-ups. These grooved wedges of pasty lava were extruded out of the bottom of an inflation cleft. Other squeeze-ups may be bulbous, linear, and smooth. Pen is 14 cm (5.4 in.) long (Devils Garden lava field).

Figure 16. This tumulus, like other tumuli, developed in the roof of a lava tube from the pressure of the molten lava within the tube. Note inflation cleft and rotated sides (Badlands lava field).

Figure 17. The surface of this pressure plateau stands nearly 18 m (60 ft) above the surrounding landscape. It was raised up by hydraulic pressure of molten lava that once underlay the entire feature. Note the wide inflation cleft that completely surrounds the elevated block (The Castle, Badlands lava field).

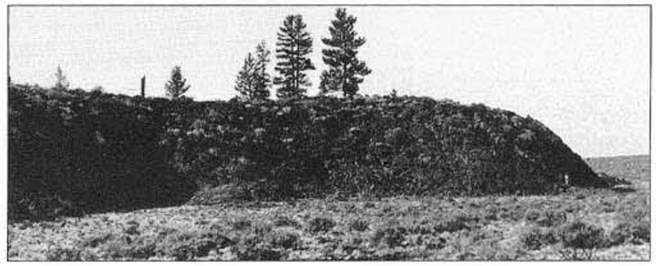

Figure 18. Side of a pressure plateau. This lava inflated to a thickness of 18 m (60 ft) from an initial thickness of perhaps 30 cm (1 ft). The side is a series of slabs of rotated crust. Note person at far right for scale (Potholes lava field).

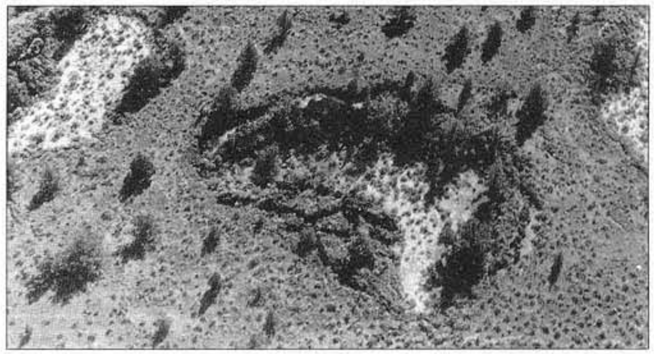

Figure 19. Example of a plateau pit. These pits develop within pressure plateaus at sites that do not inflate. Plateau pits were originally called collapse depressions, which in most cases incorrectly suggest their origin (Badlands lava field).

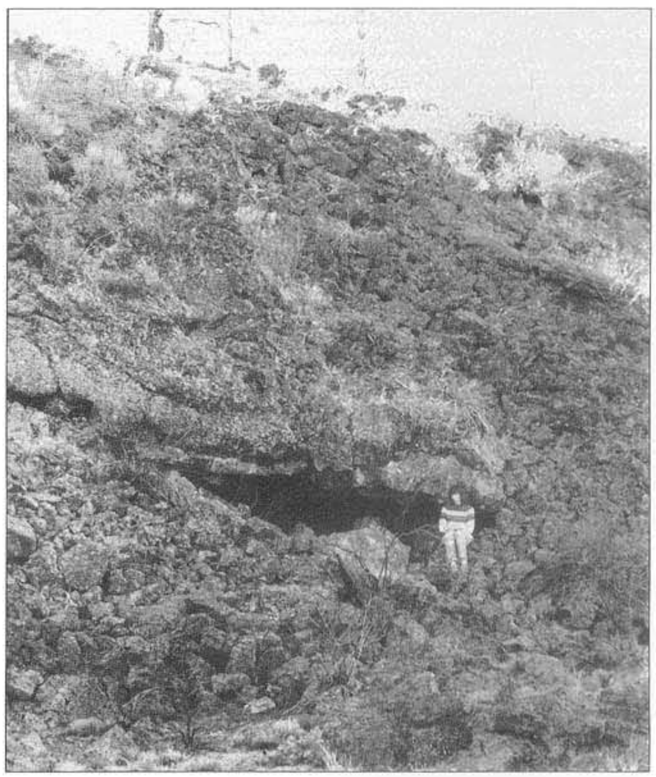

Figure 20. Example of a liftup cave. Caverns form along concave edges of flow units where blocks and columns of crust are compressed and uplifted during inflation. This liftup cave extends 7.6 m (25 ft) horizontally back from the entrance (Potholes lava field).

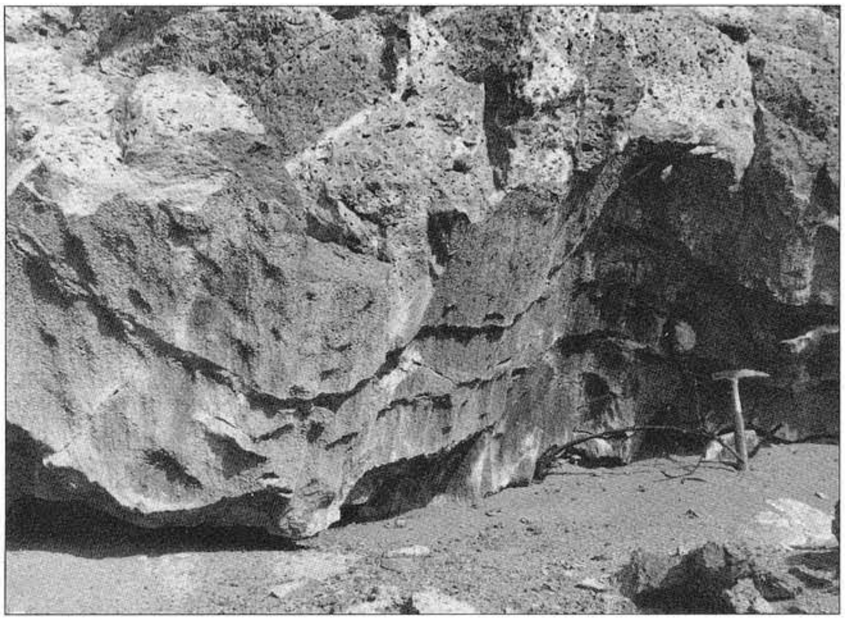

Figure 21. Example of an extrusion wall. The back wall of a liftup cave slowly extrudes at a steep angle out of the plastic region. It often displays grooves and has the appearance of draperies. Some extrusion walls are not associated with liftup caves. Note rock hammer for scale (Badlands lava field).

Figure 22. Example of accordion structure. During inflation, a series of liftup caves form one under the other in the continuously concave and circular walls of this plateau pit (Manatee Pit, Diamond Craters).

What begins as a minor, shallow low area often becomes an exaggerated and deep depression as the surrounding lava inflates. Residual depressions usually form where inflated flow units intermingle. A subsequent flow unit that fills and inflates within a residual depression can turn the depression into an elevated, positive landform—a kind of inverted topography.

A **plateau pit** is a residual depression completely within a pressure plateau (Figure 19). It may be circular or irregularly shaped with steeply sloping sides. A plateau pit is a region within a pressure plateau that did not inflate. The pit floor did not inflate due to a minor, preexisting topographic high area that either was not covered with lava or not covered to a sufficient depth to inflate with the rest of the lava of the pressure plateau.

Most features called collapse depressions by many earlier geologists are now considered to be plateau pits. A collapse depression was believed to be a collapsed part of the roof of a lava tube. Ironically, Hatheway (1971), who did a major study of collapse depressions, noted that "accessible tubes are extremely rare in terrain of collapse depressions."

A **lava tube** is a tube-shaped conduit within a solidified lava flow that is actively transporting lava, is plugged with solidified lava, or is open because lava drained away. Lava tubes form in two major ways (Wentworth and Macdonald, 1953). On steeper slopes (> 2°), lava flowing in an open channel develops a crust that becomes the roof of a lava tube. On gentle slopes (< 2°), conduits develop unseen in the complex distributary systems of inflated lava (Gillett and others, 1991) (Figure 8). Lava tubes that form in fields of inflated lava tend to develop from multiple, interconnected, and adjacent conduits.

Other important features of inflated lava are related to the shape of the edge of a flow unit. The slopes above the edge often react differently to inflation, depending on whether they occur along concave, straight, or convex edges.

During inflation at a concave edge (looking toward lava flow), the slabs, blocks, and columns of crust that make up the uplifting and tilting sides of pressure plateaus and ridges compress to form a more or less rigid, curved block that rises as a unit. A cavern, called a **liftup cave**, may open up under the rising block (Figure 20). The back wall of the cave, an **extrusion wall**, extrudes at a steep angle out of the pasty crystal mush of the plastic region (Figure 21). Sometimes, extrusion is cyclic as inflation proceeds by discrete uplifts, as evidenced by chattermarks or small ledges that mark each period of quiescence between uplifts. In a circular plateau pit where the edge of the lava is continuously concave, liftup caves may completely encircle the pit floor. Usually two or more liftup caves develop sequentially, the newer forming under the older. A group of such caves compose an accordion structure (Holcomb, 1981), a feature roughly analogous to horizontally oriented pleats in the bellows of an accordion (Figure 22 and 23).

Along straight edges, one or more inflation clefts may develop approximately parallel to the edge of the flow at the top of the rotated sides of pressure plateaus and ridges.

Above convex edges, groups of slabs, blocks, and columns of crust may spread apart during inflation. Pie-shaped wedges of rotated crust alternate with inflation clefts.

A **deflation lava cave** forms when molten lava partly or completely drains from an inflated feature such as a pressure plateau. The rigid exterior of the feature remains essentially intact. A deflation lava cave is distinguished from a lava tube by a lack of cave lining and smooth, frozen flow features. However, drainage from inflated features is uncommon.

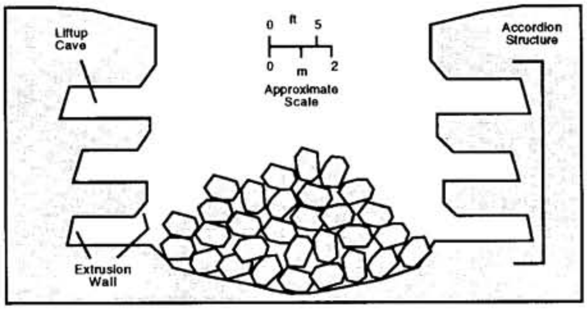

Figure 23. Generalized cross section of plateau pit in Figure 22. The position of extrusion walls shifts discontinuously and alternately from front to back of developing liftup caves. Cooling and thickening of the floor of each cave cause it to attach to the extrusion wall at the back of the cave and be lifted up.

SUMMARY

Highly fluid lava flows of basalt in central and southeast Oregon developed distinctive landforms and internal structures and textures when they erupted onto landscapes of low topographic gradient (< 2°). These lavas swelled or inflated to several times their initial thickness. Excellent examples of inflated lava can be found in the well-preserved Quaternary lava fields of Badlands, Devils Garden, Diamond Craters, Jordan Craters, and Potholes.

Lavas in these fields spread and divided in complex, tube-fed, distributary systems. The advancing fronts of active flow units slowed as lava spread into widening sectors of land. The lava eventually ceased to advance when it developed sufficient strength due to cooling to resist continued movement. The ability of this lava to inflate depended on the development of a strong, plastic region within the lava.

An inflated flow unit develops in the wake of a slowly advancing flow front, which consists of a maze of pahoehoe toes and small lobes that progressively coalesce, interconnect, develop into a continuously molten region, and then inflate.

Within inflated flow units, three vesicle zones develop from gas-saturated lava: the upper vesicular zone, middle nonvesicular zone, and lower vesicular zone. The thickness of the upper vesicular zone is related to the length of time that lava flowed through the unit. In the middle nonvesicular zone, diktytaxitic texture, vesicle cylinders, and vesicle sheets are common. Likewise, three fracture zones develop in response to cooling rates: the upper block zone, middle column zone, and lower block zone (often absent).

Inflation of lava produced distinctive landforms and structures including tilted and rotated crust, inflation clefts, tumuli, pressure ridges, pressure plateaus, plateau pits, residual depressions, liftup caves, accordion structures, extrusion walls, squeeze-ups, lava tubes, and deflation lava caves. Tumuli, pressure ridges, and pressure plateaus stand typically 1.5–18 m (5–60 ft) above their immediate surroundings. Badlands Rock, a 30-m (100-ft)-high tumulus in the Badlands lava field, is the tallest known inflated feature in central and southeast Oregon.

ACKNOWLEDGMENTS

Discussions with Robin Holcomb, Dallas Jackson, and Jim Kauahikaua of the U.S. Geological Survey were helpful and much appreciated. Field trips and discussions with Jack Lockwood and Christina Heliker of the Hawaiian Volcano Observatory and with Kathy Cashman of the University of Oregon were greatly appreciated. Bob Jensen of the Deschutes National Forest suffered through endless but helpful discussions and review. Peter Chitwood, my son, helped on many trips to lava fields of eastern Oregon and suggested the name "liftup cave."

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(Continued on next page)

BOOK REVIEW

Beautiful scenery is geology at its best!

A review of *Newberry National Volcanic Monument: an Oregon Documentary*, by Stuart G. Garrett, 1991, Webb Research Group, Medford, Oregon, 125 p.

by Lanny H. Fisk, F & F GeoResource Associates, Inc., 66928 West Highway 20, Bend, Oregon 97701

Oregon's newest National Monument now has a helpful guidebook for visitors. The author is Bend family physician Dr. Stuart Garrett, who chaired the committee that proposed National Monument status for Newberry Volcano and successfully hammered out the compromises necessary to get agreement and wide support for its designation. Dr. Garrett's book is meant to serve as a general introduction to the history and natural features of Newberry Volcano, located in central Oregon southeast of Bend. The guidebook contains chapters on "The Making of the Monument," "Cultural and Exploration History," "Geologic History," "Geothermal Resources," "Plant and Wildlife," and "Recreation Opportunities in the Monument and Outlying Areas." The book also contains a brief biography of John Strong Newberry, for whom the volcano was named, and, finally, a helpful bibliography and an index.

Although designed as a sightseer's guide, the book exceeds this usage. The author's hope that the book "will whet the appetite of visitors and will encourage them to delve deeper into the fascinating story of Newberry Volcano" will certainly be realized. As he points out, Newberry Volcano is truly "a mountain of superlatives . . . a geologic wonderland of lava flows, ash flows, pumice cones, and tuff cones,"—and a clear illustration that beautiful scenery is geology at its best!

The chapter on discovery and early exploration quotes extensively from the journals of explorers Peter Skene Ogden and John C. Fremont, which adds much liveliness to the generally interesting presentation. In 1826 Ogden wrote: "This is really a wretched country and certainly no other inducement but filthy lucre can induce an honest man to visit it . . ." Very few people would agree with his assessment today!

The chapter on geologic history, though brief, is excellent, thanks in part to the help of U.S. Forest Service geologists Larry Chitwood and Bob Jensen. For a more complete coverage, geologists will also want to pick up copies of Jensen's *Roadside Guide to the Geology of Newberry Volcano* (1988, CenOreGeoPub, 75 p.) and the *Geologic Map of Newberry Volcano* by Norm MacLeod, Dave Sherrod, and Larry Chitwood (U.S. Geological Survey Open-File Report 82-847, 1982). Dr. Garret gives fair treatment to the geology of such features as Lava Butte, Lava River Caves, Lava Cast Forest, Paulina Falls, Paulina and East Lakes, Central Pumice Cone, Big Obsidian Flow, and Paulina Peak found within Newberry Monument. He also provides geological snapshots of such nearby features as Fort Rock (a tuff ring), Hole-in-the-Ground and Big Hole (both volcanic explosion craters or maars), and Dry River Canyon (a relict Pleistocene erosional feature).

An annoying flaw of the book is the generally poor quality of the publisher's editing, including poor word divisions (such as Nor-thwest, dep-th, and hun-ting) and inconsistent spelling and capitalization (such as archeologist/archaeologist, native/Native Americans, and central/Central Oregon). Typographical errors are too numerous to mention. Awkward sentence structure is not uncommon, such as: "One of these young cinder cones and flows is Lava Butte which is near Lava Lands Interpretive Center, the top of which is easily reached by car"!

Inaccuracies are rare but exist, such as ". . . the escarpments of Hart Mountain and Steens Mountain can be observed" from Paulina Peak. Although it is true that from the top of Paulina Peak, on a clear day, observers can see both these large fault-block mountains when looking east; the *escarpments*, however, are east facing and thus *not* visible.

It is unfortunate that the maps of the Monument boundaries (p. 28) and caldera features (p. 34) are not introduced or referenced earlier in the text so that readers could use them for orientation. A map showing the locations of the outlying features described in the book would also be helpful.

However, these shortcomings do not seriously detract from the book's value to the user. It still fulfills its primary purpose well: to serve as a general guide to Newberry National Volcanic Monument. Overall, this book is a valuable compilation of information and an excellent guidebook to Newberry Volcano and the surrounding area. Anyone planning to visit central Oregon should pick up a copy of Dr. Garrett's book and read it before arrival. I bought my copy at the Nature of Oregon Information Center in Portland, but it may be available now at a bookstore near you. □

(Continued from last page)

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DOGAMI PUBLICATIONS

First digital geologic map published by DOGAMI

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released *Geology and Mineral Resources of The Elbow Quadrangle, Malheur County, Oregon*, on the geology and mineral resources for an area around northern Lake Owyhee. It is DOGAMI map GMS-62, and its purchase price is $8.

Production of GMS-62 represents a milestone in DOGAMI's publication history. It is the first DOGAMI geologic map that was prepared largely through digital (computerized) techniques by the DOGAMI staff and technical partners at the University of Oregon. It is one of the first geologic maps produced anywhere in the country in which full-color digital techniques have achieved a product that meets high standards of map quality.

The publication consists of two plates. Plate 1 includes the map, two geologic cross sections, explanations of the 26 identified rock units, and a brief discussion of the mineral resources. Plate 2 contains four tables with analytical data from over 60 samples.

Map GMS-62 is the product of the cooperative work of geologists under the leadership of Mark L. Ferns of the DOGAMI Baker City office and Michael L. Cummings of the Portland State University Department of Geology. Production was funded jointly by DOGAMI, the Oregon State Lottery, and the COGEOMAP Program of the U.S. Geological Survey as part of a cooperative effort to map the west half of the 1° by 2° Boise sheet in eastern Oregon.

Portland quadrangle hazard maps released

DOGAMI has released map GMS-79 in its Geological Map Series: *Earthquake Hazard Maps of the Portland Quadrangle, Multnomah and Washington Counties, Oregon, and Clark County, Washington.*

After Metro (the Portland area regional government) in 1993 released the *Relative Earthquake Hazard Map* of the same quadrangle, the new, more technical, multi-map publication now presents maps of the hazard aspects that were studied and combined to produce the initial map. It will be most useful to technical consultants who are concerned with earthquake safety in the construction of public buildings, bridges, and utility systems, as well as with hazard-mitigation and emergency-response.

The new publication consists of three full-color maps (scale 1:24,000) and a 106-page text. The maps depict hazard levels for liquefaction (liquefaction susceptibility and lateral spread displacement), ground motion amplification, and dynamic slope instability, as they may be produced at a given location in the quadrangle when earthquakes of various types occur. The text contains a separate chapter for each map and for the earlier relative hazard map, discussing the methods and results of the compilations and models that led to the maps.

Text and maps were authored by Matthew A. Mabey and Ian P. Madin of DOGAMI and T. Leslie Youd and Celinda F. Jones of the Department of Civil Engineering at Brigham Young University. The cartography work was done by L.D. Freedman of Metro. The studies were funded, in part, by the U.S. Geological Survey. The purchase price of GMS-79 is $20.

The new maps are now available over the counter, by mail, FAX, or phone from the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; and the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or MasterCard. Orders under $50 require prepayment except for credit-card orders.

Report on abandoned mines added to library open file

A listing of abandoned mines has been placed on library open file by DOGAMI and is available for public inspection in the DOGAMI library in Portland.

The library open file contains reports that have not been reproduced in the traditional manner of publication. Only single copies of such reports are available for inspection in the DOGAMI library, and photocopies may be obtained at cost.

Report O-93-12 is entitled *Abandoned Mines and Mills That May Be Classified as a Hazardous Waste Site Under Section 120 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)* and was produced by Jerry J. Gray of DOGAMI. It contains a computer printout that lists detailed information and hazardous-matter classifications for over 1,100 abandoned sites in Oregon.

The basis of the report is DOGAMI's database MILOC (Mineral Information Layer for Oregon by County), currently available for purchase ($25) in its recently updated version as Open-File Report O-93-8. □

Letter to the editor

Thank you so much for sending me the November issue of *Oregon Geology* in response to my inquiry concerning the Klamath Falls earthquakes. I found the article very interesting and enjoyed the whole booklet. In fact, I subscribed to it the same day I received it.

There was, however, an error on the Figure 1 Location Map on page 127 [in the article on the Klamath Falls earthquakes—ed.]. It shows Tulelake, California, as being located on Highway 97. Tulelake is actually located along Highway 139. Dorris and Macdoel are located along Highway 97.

Also, I would like to tell you I responded to your earthquake survey form right after the earthquakes. I responded that my residence did not suffer any damage. That was premature. I later found one living-room window cracked in three places and numerous cracks in the plaster in the interior of the house. These range in size from hairline to clearly visible from across the room.

Susan Crawford
Malin, Oregon

Yes, we apologize for the slip on the location map. Dorris is indeed the place that was placed on the map but then mislabeled. Tulelake actually is located some 25 mi to the east but just about as far south of the state line as Dorris. Highway 139 was not represented on the sketch map, and that may have contributed to the confusion.

We want to thank you for the correction but also for all the other good things you included in your letter! All our readers, we feel, can profit from knowing what you did: Beginning with subscribing to Oregon Geology, *reading carefully, and letting us know about it; to sending in the earthquake survey questionnaire; to pointing out that earthquake damage sometimes may not be found immediately.*

For many an editor this must appear as the model of a good reader. We hope that others will follow your example. —*ed.*

REMEMBER TO RENEW

Remember that the code number on your address label ends in four digits that identify the expiration date (month and year) of your subscription. And remember that all you need to do is use the renewal form on the last page to make sure you will continue receiving *Oregon Geology*. And remember to renew, please. By the way—why not consider a gift subscription for a friend?

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OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 56, NUMBER 2 MARCH 1994

IN THIS ISSUE:

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 56, NUMBER 2 MARCH 1994

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin.*)

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

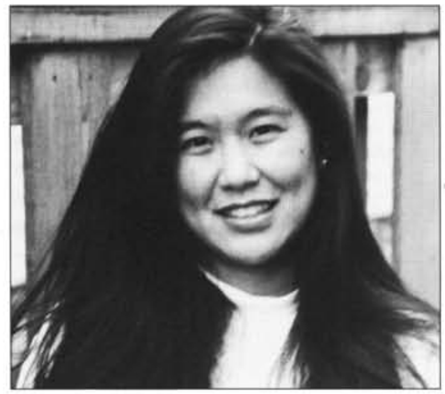
Cover photo

Yaquina Head near Newport, Lincoln County, on the central Oregon coast. This 1976 photo shows the area that in 1980 was established as an Outstanding Natural Area. Article beginning on next page presents an introduction to its geologic history.

Earthquake engineering specialist and minerals economist join DOGAMI staff

Mei Mei Wang, earthquake engineering specialist, and Robert Whelan, minerals economist, have joined the Oregon Department of Geology and Mineral Industries (DOGAMI). The two positions are supported by Oregon Lottery funds.

Wang has a master of science degree in civil engineering from the University of California at Berkeley and is continuing her studies toward a doctorate in engineering at Oregon State University. She has expertise in earthquake engineering, geological engineering, and slope and dam assessments. She comes to DOGAMI from Oakland, California, where she owned her own consulting firm, GeoLogic.



Mei Mei Wang

Most recently, she just returned from a month-long tour of Venezuela. At DOGAMI, she will be responsible for developing earthquake hazard maps for parts of the coast and of the Willamette Valley, starting with the Siletz Bay and Salem areas.

Whelan, who has a master of science degree in mineral economics from Pennsylvania State University, has experience in business and market research, economic forecasting, strategic planning, business development, and technology assessment. He has worked with

Robert Whelan

Chase Econometrics, Climax Molybdenum, and Nerco, Inc., as economist, market research analyst, and director of business analysis and development. Most recently he was a private consultant in Portland. His responsibilities at DOGAMI will be to do a regional analysis of demand for aggregate minerals, to develop mineral production statistics for the state of Oregon, and to find marketing opportunities for Oregon industrial minerals to be used in environmental protection applications. □

A geologic overview of Yaquina Head, Oregon

by Cheryl L. Mardock, Albany Research Center, U.S. Bureau of Mines, Albany, OR 97321-2198

ABSTRACT

Yaquina Head is a distinct promontory located approximately 3 mi north of Newport on the Oregon coast. The headland is a distal lobe of the Ginkgo basalt, a flow of Wanapum Basalt of the Columbia River Basalt Group. This unique setting was established as an Outstanding Natural Area in 1980 to preserve its natural, scenic, historic, scientific, educational, and recreational values. The U.S. Bureau of Mines, in a cooperative agreement with the U.S. Bureau of Land Management, provided a nontechnical interpretation of the area's geology for exhibits that are scheduled to be completed in August 1995.

The geologic features at the site are exceptional. Impressive exposures of columnar basalt and local faulting are evident even to the untrained eye. The explosive confrontation between the Columbia River basalts and the Pacific Ocean is recorded in the exposed rocks of the cliffs and beaches. Uplift and sea-level changes have carved multiple terraces into the headland, and superb examples of faults, folds, joints, dikes, and erosional features are exposed at the site.

INTRODUCTION

Yaquina Head is located on the extreme western edge of the Coast Range physiographic province in Lincoln County along the north-central portion of the Oregon coast (Figure 1). The boundaries of the landform lie within secs. 29 and 30, T. 10 S., R. 11 W., Willamette Meridian. Newport is approximately 3 mi to the south, Agate Beach is adjacent to the east, and Beverly Beach is 3 mi to the north. Access is by Lighthouse Drive, a mile-long paved road off U.S. Highway 101, the major north-south highway along the Pacific coast. Figure 2 shows an aerial view of Yaquina Head with geologic feature locations marked for reference.

From 1917 to the late 1970s, Yaquina Head provided a unique source of competent rock for road material. Rocks from other flows in the region proved to be fragile and unserviceable because they are rich in swelling clays. There are two major quarries on the headland: an upper quarry near the summit of the headland and a lower quarry on the south side near sea level. Their large size attests to the many years that this basalt supplied an invaluable resource for building the local infrastructure including Highway 101. Efforts to close the quarries to preserve the profile of the headland stimulated action to create the Yaquina Head Outstanding Natural Area. The quarries' walls now provide superb windows onto the geology of the headland.

Public Law 96-199 created the Yaquina Head Outstanding Natural Area on March 5, 1980, to serve as a basis for managing the natural, scenic, historic, scientific, educational, and recreational values of Yaquina Head. Managing agencies include the U.S. Bureau of Land Management (BLM), the U.S. Coast Guard, the Oregon Department of Parks and Recreation, and the U.S. Fish and Wildlife Service. When development is completed, the area will feature the unique combination of an interpretive center, tidal-zone marine gardens, geologic features and exhibits, archaeological exhibits, the Yaquina Head lighthouse, harbor-seal rocks, seabird rookeries, shoreline and freshwater-marsh ecosystems, a whale-watching observation area, and the Fishermen's Memorial.

U.S. Bureau of Mines geologists had the pleasure of interpreting the geologic story of the headland for BLM's proposed Interpretative Center Complex. The resulting general geologic overview is the most comprehensive work done to date on Yaquina Head. Perhaps this groundwork will encourage other geologists to do more in-depth studies of this exceptional site.

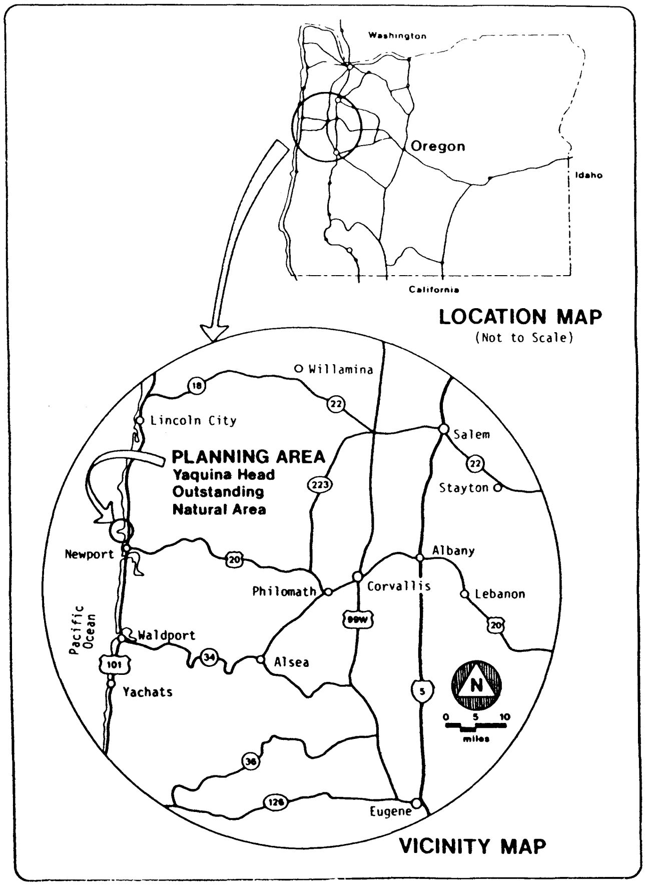


Figure 1. Location of Yaquina Head Outstanding Natural Area.

THE GEOLOGIC STORY

Fire fountains erupt in Oregon, Washington, and Idaho

Between 12 and 16 million years ago during middle Miocene time, huge floods of basalt lava flowed out of great fissures in eastern Oregon, southeastern Washington, and western Idaho. Like fountains of fire, flood basalts surged from chains of fissures up to 50 mi long, filling low-lying areas and eventually reaching the western coastline of Oregon (Beeson and others, 1985). The flows remained fluid over a journey stretching in excess of 300 mi because their immense volume allowed the flows to retain their heat and because the basalt was low in silica and consequently low in viscosity. The lava flowed over much of northeast Oregon and southeast Washington. The flow that traveled to Tillamook Head, Cape Falcon, Cape Meares, Cape Lookout, Cape Kiwanda, Depoe Bay, Yaquina Head, and Seal Rock (Figure 3) flowed westward, through the Columbia River Gorge, and down an ancient Columbia River channel to the northern and central Oregon coast (Tolan and others, 1984; Orr and others, 1992). The Columbia-Snake River basalt plateau covers an area of about 200,000 mi^2; it has an average thickness of 3,000 ft and a maximum thickness of 15,000 ft (Reidel and Hooper, 1989).

The Ginkgo basalt

The basalt at Yaquina Head was previously called the Cape Foulweather Basalt when it was believed that this basalt flowed

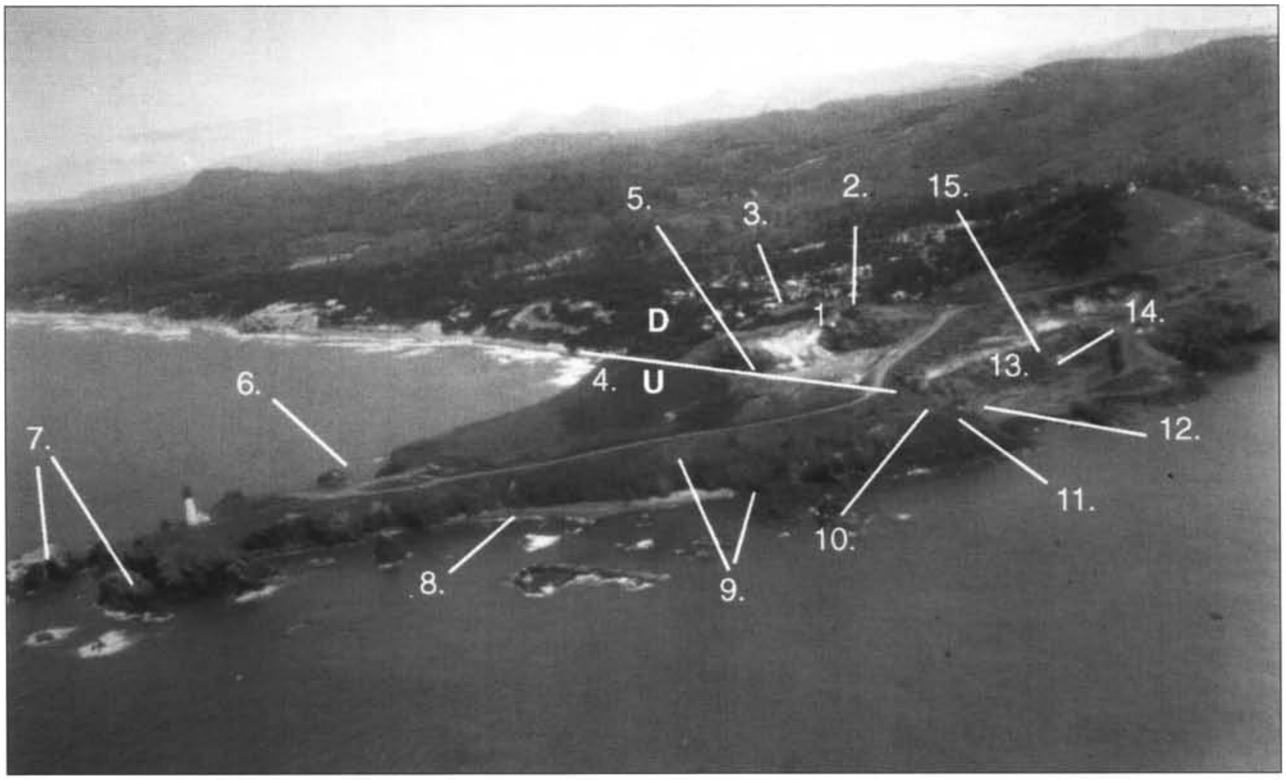


Figure 2. Aerial view of Yaquina Head shows geologic features: (1) upper quarry; (2) eolian sands; (3) colonnade; (4) large fault, U = upthrown side, D = downthrown side; (5) spheroidal weathering feature; (6) arch; (7) erosional features; (8) cobble beach; (9) dikes; (10) breccia; (11) uplifted beds; (12) colonnade; (13) lower quarry; (14) entablature; (15) small fault. Modified from photo courtesy U.S. Bureau of Land Management.

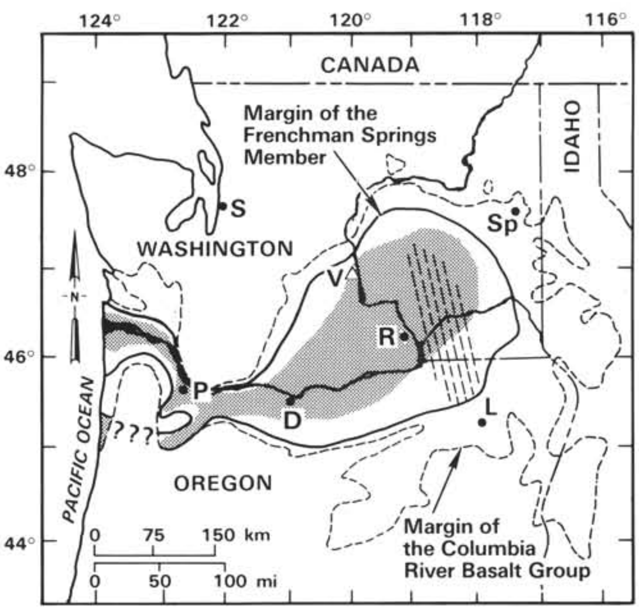


Figure 3. Inferred original extent (stippled area) of the basalt of Ginkgo, a flow of the Frenchman Springs Member of the Columbia River Basalt Group. Dike and vent area is shown schematically by parallel dashed lines. Open triangle designates location of type locality. Abbreviations for cities: D = The Dalles; L = LaGrande; P = Portland; R = Richland; S = Seattle; Sp = Spokane; V = Vantage. From Beeson and others (1985).

from a local coastal volcano (Snavely and MacLeod, 1971; Snavely and others, 1973). Studies now indicate that the basalt is the basalt of Ginkgo, a flow of the Frenchman Springs Member of the Wanapum Basalt in the Columbia River Basalt Group (Beeson and others, 1979; Beeson and others, 1985). The Ginkgo basalt at Yaquina Head is tholeiitic; it contains volcanic glass and little to no olivine and has orthopyroxene, clinopyroxene, and calcium plagioclase. The groundmass is a combination of glass and fine- to medium-grained crystals; it is sparsely microporphyritic and contains both tabular and acicular plagioclase microphenocrysts.

Although all of the basalt on Yaquina Head came from the same source and has the same chemistry and mineralogy, it has very different morphology resulting from a range of complex cooling environments. Geomorphic forms include columnar basalts, breccias, and smooth, unjointed basalt. Faulting, folding, weathering, and erosion have further changed the basalt across the headland.

Columns

Columnar basalt occurs in numerous areas on Yaquina Head, including the eastern halves of both the upper quarry and lower quarry walls. The columnar appearance is due to jointing caused by shrinkage cracks that formed perpendicular to the cooling surface. The joints separate the basalt into columns with four to eight sides, but usually six sides. Basalt from both near the air-cooled surface and near the ground-cooled surface of the lava flow forms sets of thick, vertical, and parallel columns called colonnades. There are no sizable colonnades exposed on Yaquina Head. Small exposures include a short (approximately 3-ft-high) colonnade at the top of the eastern side of the upper quarry back wall and a small rock-island colonnade that lies in the sea entrance at the northern end of the lower quarry (Figure 4).

The columns in the lower quarry wall and much of the eastern side of the upper quarry wall are thinner than the colonnade columns and are oriented at varying angles, often forming irregular shapes resembling fans, chevrons, and rosettes (Figure 5). This phenomenon, called entablature, is characteristic of the central part of thick basaltic lava flows. One of the theories of its formation is that, as the flow cooled from the bottom and top, irregular cracks penetrated into the middle part of the flow. This created disarrayed cooling surfaces and caused the basalt to joint in complex patterns.

Figure 4. A small colonnade (mid-picture) at the sea entrance to the lower quarry is isolated by a fault from tectonically uplifted layers of hyaloclastic pillow breccia (upper part of picture) on the north wall of the lower quarry.

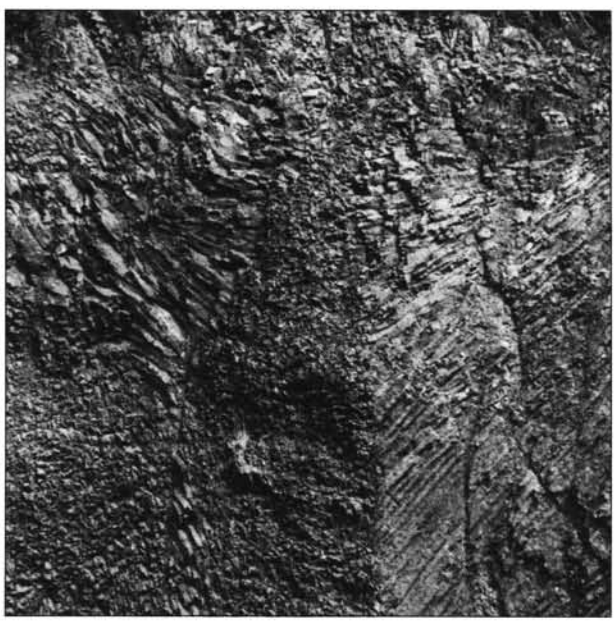


Figure 5. The lower quarry wall is an exceptional example of disarrayed columns forming complex chevrons, fans, and rosettes in the middle of a thick basaltic lava flow. View area is about 15 ft^2.

Breccia

The volcanic rock that is exposed along much of the southern beach area is a glassy basaltic breccia composed of both angular and well-rounded fragments of basalt and glass shards within both mineral and glass matrices. Most of the fragments in this breccia are less than an inch in diameter, but some large clasts are more than 6 ft wide. The breccia formed as the lava flowed into the ocean and either boiled and frothed or explosively fragmented as it quenched in the seawater.

Some of the breccia components are broken, blocky, angular fragments of finely crystalline, scoriacious, or glassy basalt. Some of the lava formed smooth, ellipsoidal, toelike, or pillow-shaped globs as it dropped into the sea—in much the same way as salad oil forms globs when poured into vinegar (Snavely and MacLeod, 1971). These pillows differ from undersea-extruded pillows in their distinctive small size and truncated forms.

The resulting composition of these unstratified, unsorted breccias (Figure 6) is one of variably sized and shaped lithic fragments of basalt, including broken and unbroken pillows, in a matrix of smaller fragments, spherules, glass, glass shards, and palagonite, a mineraloid created nearly instantaneously by hydration of the glass as soon as it enters the sea (MacDonald, 1972; Cas and Wright, 1987). The rock may be best described as a palagonitic pillow breccia (A.R. McBirney, University of Oregon, personal communication, 1994). Other scientists have called this type of rock "flow-foot breccias" (Jones and Nelson, 1970), "hyaloclastites" (Cas and Wright, 1987; Rittmann, 1962) "broken-pillow breccias" (Williams and McBirney, 1979), and "aquagene tuffs" (Carlisle, 1963).

The rind of the pillows is basaltic glass that formed by sudden quenching of the globs of lava. Most of these rinds have been altered to palagonite. The interior of the pillows, insulated by the chilled rinds, slowly solidified to felty-textured, finely crystalline basalt as the pillows settled amid the other fragmental material.

Mud, sand, and gravel also were incorporated into the breccia as the lava mixed with boiling, water-saturated sea-floor sediments.

Molten lava, glass, and palagonite cemented the solidified lava fragments, glass shards, pillows, and sediments together.

These palagonitic pillow breccias form a fringe around the seaward edge of the lava flows. They also lie below the dense,

Figure 6. Palagonitic pillow breccia along the shoreline is being eroded away, leaving resistant cobbles.

crystalline basalts that comprise much of Yaquina Head because they were laid down when the flows first encountered the sea, perhaps near where the headland begins. As the breccia filled the shore area, subsequent lava flowed over it as if on dry land, until the flows again reached seawater. This layered formation is known as a lava delta (Jones and Nelson, 1970).

Aa and pahoehoe

In addition to the palagonitic pillow breccia, there is some flow breccia (aa) formed by air cooling. As the surface of the moving flow cooled and solidified, the cooled skin of solid basalt continuously broke into fragments that tumbled along to intermix with the now-viscous lava beneath. The flow breccia may be identified because it has a relatively low glass and palagonite content and lacks pillows. Smooth, ropy, fluid pahoehoe also flowed over Yaquina Head. However, most of the sinuous surface features of this flow type have been eroded and are difficult to see.

Dikes, lobes, tongues, and sills

As the basalt flowed into the sea, it ponded in the bays and estuaries, and these ponds became so heavy that lava was forced downward into the underlying, water-saturated sediments. Layers of sediment were either gently lifted to the top of the lava or were fragmented and forced aside or intermixed with the basalt. The flows also created smooth, tabular dikes and sills as well as irregular dikes, lobes, and tongues of solid, unfragmented lava, mixtures of basalt and sedimentary material, or breccia within the sediments (Beeson and others, 1979). Similar bodies of dense basalt also intruded the basaltic debris (breccia) before it solidified.

Lava, sand, and mud

The basalt overlies sedimentary sandstone and siltstone of the lower Miocene Astoria Formation that form the buff-colored sea cliffs north and south of the headland. A contact between the Ginkgo basalt and the Astoria Formation is clearly exposed in the cliffs at the ends of the beaches on both sides of Yaquina Head. The Astoria Formation is famous for its fossil sharks' teeth and bones of turtles, whales, seals, and sea lions, as well as crabs, mollusks, corals, barnacles, and brachiopods (Orr and others, 1992). Accumulation of the Astoria Formation marine sands stopped when the land was uplifted, the sea retreated, and the basalt flows invaded the area (Snavely and others, 1973). Below the Astoria Formation lies the early lower Miocene Nye Mudstone (Snavely and others, 1964; Lund, 1974). These olive-gray mudstones and siltstones were deposited when the land was submerged, and mud and silt, rich in organic material, were deposited in the deep water. Modern eolian (wind-deposited) dune sands now cover parts of the basalt, sandstone, mudstone, and marine terraces (Figure 7).

Tectonics

Although the sedimentary rocks and breccia were deposited in water in nearly horizontal strata, most of them are now inclined 10° to 20° in a westward direction (Snavely and MacLeod, 1971) (Figure 4). The strata are folded and faulted (Snavely and others, 1980). A major episode of regional uplift occurred 14 million years ago, when the Juan de Fuca Plate pushed under the North America Plate, forcing the rocks of the continent to fold and fault. Immediately north and south of Yaquina Head, this inclination is clearly exposed in the tilted sandstones of the Astoria Formation. An exposure of similarly inclined layers of breccia may be seen at the north side of the entrance to the lower quarry.

Ice ages, continental uplift, and terraces of sand

The surf has cut platforms or terraces at different elevations as the level of the shoreline changed over the years. These changes resulted from continental uplift and changes in sea level that occurred during the Pleistocene ice ages between 8,000 and 3 million years ago. As the water level rose to cover the platforms, sediment was deposited. As the sea level again dropped or the coastline was uplifted, the terrace deposits were left behind. Sediments now rest on an ascending flight of platforms ranging in elevation from 40 to 500 ft above present sea level. These Pleistocene terrace deposits, mainly sand and pebble beds that include some organic materials, are well exposed on the basaltic sea cliffs between Yaquina Head and Otter Crest, a small cape 7 mi to the north.

Figure 7. Eolian sands cover much of the basalt of the upper quarry wall.

Figure 8. A fault divides the columnar basalt wall of the lower quarry from the uplifted beds on the lower quarry's north wall.

Faults

Between the western (seaward) uplifted beds and the eastern columnar basalt wall in the lower quarry is a soil-covered fault trace (Figure 8). The fault may also be traced through the central back wall of the upper quarry, where it divides the breccia on the western wall from the columnar basalt on the eastern wall. The seaward side of the fault is upthrown, and the inland side of the fault is downthrown. This fault strikes roughly north-south and is one of a series of regional north-trending, high-angle, eastward-dipping, normal en-echelon faults that resemble a flight of steps. These en-echelon faults parallel the coastline for at least 15 mi north of Newport. This zone of normal faulting is astride the "hinge line" between areas of post-late Miocene subsidence in the deep marginal basin and uplift in the Coast Range (Snavely and others, 1980).

Another normal fault that appears to displace the columnar basalt by approximately 20 ft may be seen in the lower quarry wall (Figure 9).

Figure 9. A small normal fault in the lower quarry wall appears to displace the columnar basalt about 20 ft.

Stacks, reefs, arches, and rock knobs

Yaquina Head was considerably larger in the past and has suffered intense erosion by the surf. Differential weathering, due to either rock cohesion or fracture patterns, has resulted in the present irregular outline of Yaquina Head. As erosion progressed, the resistant rocks were separated from the mainland and are now the stacks, reefs, and rock knobs seen offshore; an erosional arch is carved into the northern side of the headland.

The softer sedimentary rocks and breccia have been eroded to expose many of the dense, resistant basalt dikes and sills. The dikes are aligned perpendicularly with the coastline and may be recognized as the ridgelike rocks that jut out into the sea (Figure 10).

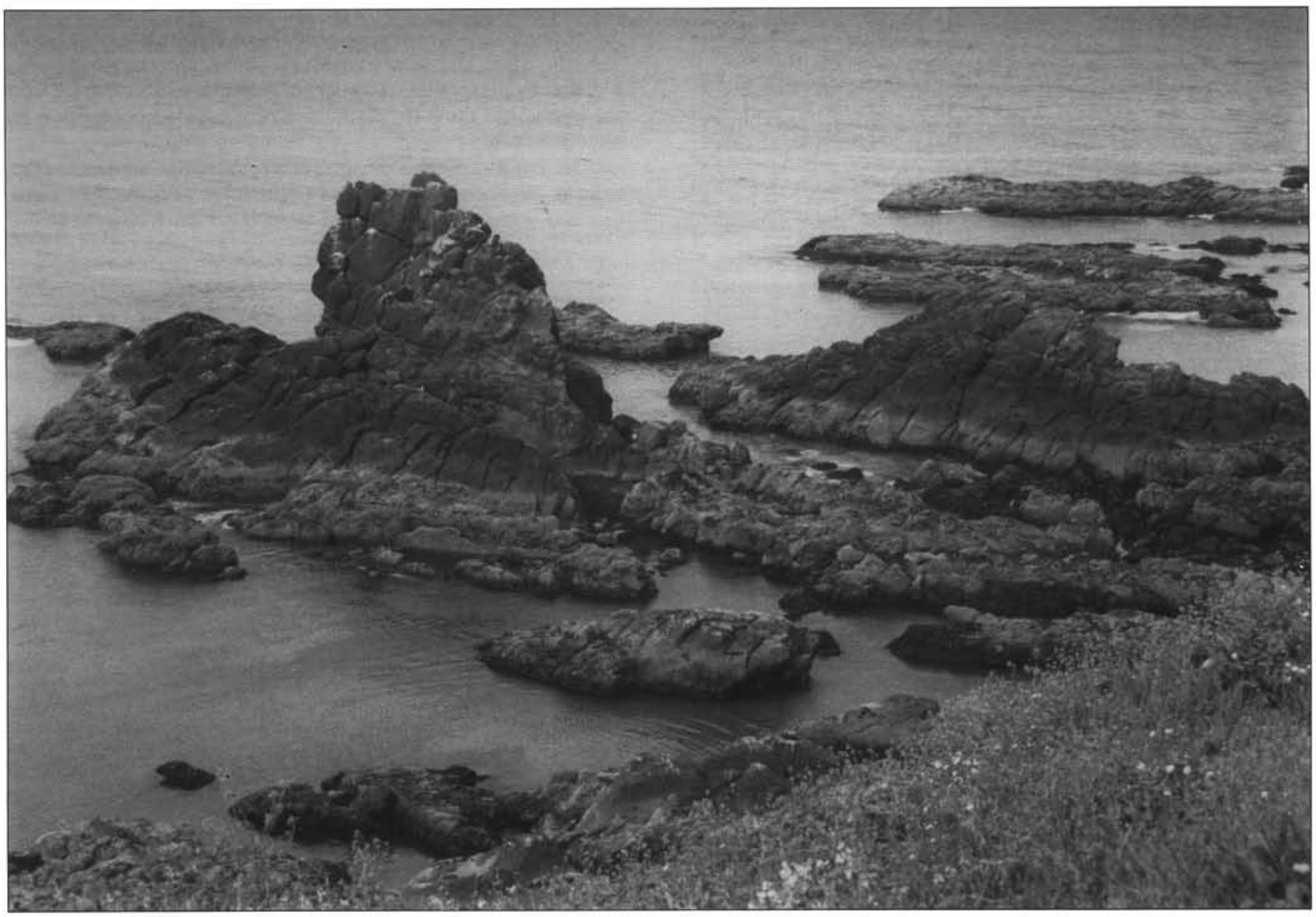


Figure 10. The ridgelike rocks that jut into the sea are resistant dikes of solid basalt. Photo courtesy U.S. Bureau of Land Management.

Spheroidal weathering phenomenon

As jointed basalt weathers, it sometimes spalls off in successive shells, like the skins of an onion, around a solid rock core. This spalling, or exfoliation, is caused by physical and chemical forces that produce differential stresses within the basalt. When spalling begins, the outermost shells are bounded by sets of nearly parallel joint planes present in the basalt. Water moves slowly along these intersecting joint sets, altering constituents such as feldspars and glass in the basalt to more voluminous secondary minerals. The innermost shells are more spherical as the rock becomes reduced in size and the corners more rounded (Skinner and Porter, 1989). This phenomenon may be seen at the top of the north cliff face of the upper quarry (Figure 11).

Figure 11. Biscuitlike erosional features are the product of spheroidal weathering of the basalt wall of the upper quarry.

Cobbles, pebbles, and sand

The beach at Yaquina Head Outstanding Natural Area is small and is often exposed to high-energy Pacific storm waves. As the abundant, less resistant, glassy breccia matrix was eroded, it disintegrated to sand and silt, and the dense, resistant crystalline-basalt fragments and pillows were released and concentrated by waves into beach cobbles and pebbles (Figure 12). The unique ellipsoidal to spherical shape of the cobbles is a result of the original blocky to pillow-shaped forms of the breccia fragments. Both fragmental types are surrounded by either palagonite or easily weathered glass. This offers the opportunity for water to channel around the blocks and pillows, further rounding them, in situ, through the spheroidal weathering process. The action of the surf further rounds and sorts these sturdy rocks. These cobbles, therefore, differ from the more common, flatter beach cobbles that are formed from erosion of more massive, homogeneous rock on many Oregon beaches. (The cobble beach is accessible on the south side of the promontory. The unusual roundness of the cobbles requires that visitors take special care to avoid falling when walking the beach at Yaquina Head Outstanding Natural Area. Note also that visitors are prohibited from taking samples so this unusual beach deposit may be preserved.)

Sand accumulates on the cobble beach during summer, but most of it is swept out to deeper water during winter storms. Some of the sand is pushed northward by longshore currents. In many places on the beach, the bedrock is swept clear, and in others the beach deposit is mostly cobbles and pebbles.

Secondary minerals

Much of the basalt shows evidence of chemical weathering. Palagonite, a pale-yellow to orange, fibrous to gel-like, hydrated mineraloid, is a weathering product of the highly susceptible volcanic glass and seawater. Much of the breccia is cemented together by palagonite, and many of the large rocks offshore from the lighthouse show the distinctive brown coloration of palagonite alteration.

The basalt contains several other alteration minerals. Iron-bearing minerals have oxidized to limonite, goethite, and hematite, and some of the aluminum-bearing minerals have altered to

Figure 12. Cobbles, pebbles, and sand are constantly shifted and sorted by wave action on the cobble beach.

Figure 13. Minute, delicate zeolite crystals line cracks and vesicles in the basalt.

small, delicate, gold, green, white, or colorless crystals of zeolites (Figure 13). Other alteration minerals include various clays and chlorite. Secondary calcite, recrystallized from primary calcite that was dissolved from the surrounding sedimentary rocks, forms white to colorless crystals on some of the basalt surfaces. Tiny crystals of all of these alteration minerals may be seen in vesicles in the basalt, and the zeolites and calcite may completely fill larger cavities.

CONCLUSION

The Yaquina Head Outstanding Natural Area offers a unique opportunity for the lay visitor to see the results of volcanic, sedimentary, geomorphic, and tectonic processes. The geologic history of Yaquina Head is a fascinating story that can be read in the exposed rocks. The story chronicles the fiery beginnings of the lava 300 mi to the northeast, the explosive confrontation of molten lava with the ocean, the processes of flowing and cooling lava, the movement of the earth's plates, and the continuing processes of weathering and erosion. The expected 600,000 visitors per year should come away from the area with an appreciation for the many geologic processes that have formed and continue to shape our world.

ACKNOWLEDGMENTS

I would like to thank U.S. Bureau of Mines geologists Cathy Summers and René LaBerge, photographer Steve Anderson, and University of Oregon volcanologist Dr. Alexander McBirney for their generous assistance in this endeavor. I am most grateful to Geologist Singh Ahuja, and Interpretative Specialist Jack Delaini, both of the U.S. Bureau of Land Management, Salem District, for giving us the opportunity to define this interesting geologic feature and for freely offering their transportation, support, and encouragement. Reviewers David Dahlin, Carl Almquist, and Carla Kertis of the Bureau of Mines provided many invaluable comments and suggestions.

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USGS offers new teacher's packets

The U.S. Geological Survey (USGS) has produced two teacher's packets that can help upper elementary and junior high school students understand and use maps and introduce them to the concept of global change.

The packet *What Do Maps Show?* contains a teaching poster, background information and four lesson plans for the teacher, and reproducible maps and activity sheets for student packets.

The poster shows one location, Salt Lake City, in several pictures and symbolic representations, including aerial photography; shaded-relief, topographic, and road maps; and a (three-dimensional) terrain model created from computerized data. It provides visual support for the major points of the lessons: that there are different types of maps; what information is needed to read maps (such as direction, latitude, longitude, scale, and map legend); and how two-dimensional maps can represent three-dimensional surfaces.

The packet *Global Change* contains a teaching poster, background information, and three lesson plans for grades 4–6, introducing this relatively new area of scientific study under the concepts of "time," "change," "cycles," and "Earth as home." The activities include learning how to read tree rings, how to understand concentration and measurement in parts per million, and how to consider "Earth as home" as an ecosystem in which changes in one part can cause changes to other parts. For each of the activities, illustrations on the poster provide large-scale visual support.

The packets are available through the Earth Science Information Centers (ESIC), including the Oregon Department of Geology and Mineral Industries Nature of Oregon Information Center (see back cover of this issue) and the USGS ESIC at W. 904 Riverside Avenue, Spokane, Washington 99201, phone (509) 353-2524. □

AGI offers services for educators

The American Geological Institute (AGI) announces that it has received a grant from ARCO to help support the ongoing program of the Earth-Science Education Clearinghouse. AGI established the clearinghouse in 1993 to provide an effective system for disseminating information about earth-science educational materials and activities.

With such industry support, AGI has just produced its first Clearinghouse product for the public, the *Earth-Science Education Resource Directory*. The first edition of this directory contains information on more than 125 organizations with more than 350 products that run programs, produce classroom resource materials, and supply related earth-science activities in the content areas of atmosphere, biosphere, hydrosphere, lithosphere, and space science. That information comes from the Clearinghouse database on earth-science organizations and educational resources. The database is one of the resources that Clearinghouse staff members use in responding to some 10,000 information requests annually.

A leader in earth-science education since the 1950s, AGI is heading a major effort in developing modern curriculum materials and associated teacher-enhancement programs. In this effort, AGI is working with its member societies and other earth-science organizations. Requests for information from the Earth-Science Education Clearinghouse or about the AGI education and human-resources programs should be addressed to Education and Human Resources Department, American Geological Institute, 4220 King St., Alexandria, VA 22302-1507, or by phone to (703) 379-2480. The Internet number is ncese@aip.org.

AGI also offers *Careers in the Geosciences*, a full-color flyer describing what geoscientists do and where they work, future job prospects, salary figures, and sources for more information. The flyer, suitable for students 12 and older, is available from the National Center for Earth-Science Education, and up to 10 copies are free from AGI (address above). For more than 10 copies, phone the AGI Publications Center at (703) 953-1744.

From AGI releases

GSA 1994 Annual Meeting to be held in Seattle

The Geological Society of America (GSA) will hold its Annual Meeting October 24–27, 1994, in Seattle, Washington. More than a dozen associated societies will also participate in the meeting.

For papers to be presented, abstracts are due July 6. Copies of the required current abstract forms are available from most university geology departments and GSA Campus Representatives, offices of the U.S. Geological Survey and many corporations, symposium conveners, GSA section officers, or the GSA Abstracts Coordinator. The address of the GSA Abstracts Coordinator is, for U.S. Mail, P.O. Box 9140, Boulder, CO 80301-9140 or, for Express Service, 3300 Penrose Place, Boulder, CO 80301.

For further information, contact the GSA Meetings Department, P.O. Box 9140, Boulder, CO 80301, phone (303) 447-2020 or (800) 472-1988. □

Cordillera meeting set for April 1995

An invitation and call for papers has been sent out by the Geological Society of Nevada for the symposium "Geology and Ore Deposits of the American Cordillera," to be held April 10–13, 1995, at John Ascuaga's Nugget in Reno/Sparks, Nevada. The symposium is cosponsored by the Geological Society of Nevada and the U.S. Geological Survey.

The symposium will focus on the metallogeny of the American Cordillera from the Precambrian to the present and the role that depositional, tectonic, and magmatic events have played in the formation of ore deposits of the region. Sessions are being planned to cover a broad range of geologic environments and deposit types and will include oral and poster sessions, workshops, core displays, and field trips.

Papers may be submitted concerning all aspects of ore deposits of the Cordillera and related geological topics. Abstracts are requested by April 1, 1994; deadline for accepted papers will be October 1, 1994.

For further information, contact the Geological Society of Nevada at P.O. Box 12021, Reno, Nevada 89510, phone (702) 323-3500. □

SEPM renames journal

After renaming its organization some time ago, the Society for Sedimentary Geology (still carrying the acronym SEPM—for the original name "Society of Exploration Paleontologists and Mineralogists") has renamed its journal: The *Journal of Sedimentary Petrology* is now the *Journal of Sedimentary Research*. The new journal will have eight issues published in two sections: Section A, "Sedimentary Petrology and Processes," focuses on sedimentology, petrology, geochemistry, and processes; Section B, "Stratigraphy and Global Studies," focuses on broader aspects of sedimentary geology, such as stratigraphy and sedimentary basins. For more information, call (800) 865-9765. □

Formosa Exploration begins closure of Silver Butte Mine

Formosa Exploration of Vancouver, British Columbia, Canada, has begun reclamation of its Silver Butte Mine and cleanup of damage to Middle Creek in Douglas County. The work is being monitored by the Oregon Department of Geology and Mineral Industries (DOGAMI) and the Oregon Department of Environmental Quality (DEQ). The Oregon Department of Fish and Wildlife is also involved with the cleanup.

During routine inspections of the site by the agencies, numerous permit violations were discovered. Included in the violations were illegal disposal of zinc concentrates, illegal disposal of sulfide-bearing waste rock, diesel fuel spills, overfilling of water-storage ponds with water and mill tailings, and uncontrolled discharges of sulfides into Middle Creek. After a review of the work needed to put the site into compliance with the state permits, Formosa decided to cease mining operation and reclaim the site. Reclamation of the mine site and remediation work in Middle Creek are now in progress.

The Silver Butte Mine is located southwest of Riddle in Douglas County. After extensive exploration and permitting activities, the site was permitted by DOGAMI and DEQ in 1990. Operations of the mine and mill were designed to recover copper and zinc from the ore to be mined at a rate of approximately 200 tons per day. Mining continued from 1990 until August 1993, when mining ceased and reclamation began.

The reclamation security prior to the violations was $500,000, the statutory maximum. That amount was raised to $980,000 after DOGAMI and DEQ discovered the violations and evaluated the amount of reclamation required under the permits. Bond reductions are anticipated as work is completed. Some of the bond money will be held for at least three years to guarantee that the reclamation work has been accomplished successfully. □

Letter to the editor

[Regarding report on reader survey in the November 1993 issue. By William E. Eaton, Eugene]

I am calling to object.

What I still like to call the "Ore Bin" is a great publication for Oregonians. I read the results about ads, widening to the PNW, etc.

You say many readers made helpful comments. I saw no reference to its [the magazine's] former colorful name, nor ever a decent explanation/need for a name change. Is it more "PC"? Is a down-to-earth name bad appearance?

Let's make this a "Letter to the Editor" and see what replies you receive.

Sincerely,
Bill
"The Old Camper"

In explanation: The Oregon Department of Geology and Mineral Industries began to inform the public in the beginning (1937–1939) through "Press Bulletins." Volumes 1 through 40 (1939–1978) of Oregon Geology *were published under the title* Ore Bin. —*ed.*

Oil and gas exploration and development in Oregon, 1993

by Dan E. Wermiel, Petroleum Geologist, Oregon Department of Geology and Mineral Industries

ABSTRACT

Oil and gas leasing activity declined during 1993. Four U.S. Bureau of Land Management (BLM) lease sales were held, but no leases were purchased. There were no over-the-counter filings for BLM leases during the year. The total number of federal acres under lease at year's end was 5,491 acres. The State of Oregon conducted no lease auctions during the year. The total number of State of Oregon acres under lease at year's end was 25,520. Coos County leased 8,212 acres at a lease sale held during the year. Columbia County granted natural gas storage rights on 960 acres.

Thirteen exploratory wells and three redrills were drilled during the year. Two of the exploratory wells were operated by Carbon Energy in the Coos Basin and are suspended pending further evaluation. The remaining wells were drilled at the Mist Gas Field by Nahama and Weagant Energy; five of the wells were successful gas wells, and the others were plugged and abandoned.

Twenty-one wells were productive at Mist Gas Field during the year, and six suspended wells awaited pipeline connection at year's end. A total of 3.5 billion cubic feet (Bcf) of gas was produced during 1993 with a value of $7.1 million.

The Oregon Department of Geology and Mineral Industries (DOGAMI) completed a study of the Tyee Basin located in Douglas and Coos Counties. Several maps and reports have been published on the oil, gas, and coal resources of the area, and the final study summary and geologic map will be released in the near future.

DOGAMI and the Northwest Petroleum Association (NWPA) sponsored a series of meetings at which the U.S. Geological Survey (USGS) and Minerals Management Service (MMS) discussed the ongoing national assessment of undiscovered oil and gas reserves. A celebration was held at Mist Gas Field to recognize that over $100 million from natural gas production was reached during the summer of 1993.

LEASING ACTIVITY

Leasing activity declined during 1993, which is a continuation of a trend that began during the late 1980s. Activity included four public sales by the BLM, and no bids were received at these sales. BLM received no over-the-counter lease filing applications during the year. Federal acres that expired, were terminated, or had pending offers withdrawn during the year totaled 29,819 acres in Oregon. The total number of federal acres under lease in Oregon at the end of 1993 amounted to approximately 5,491 acres located primarily in Jefferson and Crook Counties. Total rental income for the year was about $6,000. At year's end, applications on 28,231 federal acres located in Jefferson County were pending.

The State of Oregon held no lease sales during the year. The total number of State of Oregon acres under lease at year's end was 25,520 acres, about the same as at the end of 1992. Total rental income was about $25,520.

Coos County held an oil and gas lease sale in March, at which leases covering 8,212 acres were acquired by Carbon Energy of Kent, WA. The leases are in the Coos Basin, Coos County. Total income was $8,212.

Columbia County granted natural gas storage rights to Nahama and Weagant Energy on 960 acres for the minimum required bonus of $20 per acre for a total of $19,200. Columbia County held no other lease sales during the year.

Drilling operation at the Nahama and Weagant well LF 43-32-65, which was drilled by Taylor Drilling Company Rig 7 and was completed as a gas producer during 1993 at the Mist Gas Field. The well produced gas at a rate of over 2 million cubic feet per day during its first month of production.

DRILLING

Thirteen exploratory gas wells and three redrills were drilled in Oregon during 1993. This is an increase from the five exploratory wells and two redrills drilled during 1992. All but two of the wells were drilled at the Mist Gas Field, Columbia County, where most of the state's oil and gas drilling activity has occurred since the field was discovered in 1979. The other two exploratory wells were drilled by Carbon Energy Company in the Coos Basin about 10 mi south of Coos Bay. These two wells were drilled for coal-bed methane, which may be generated and trapped in coal beds. Both wells, the Coos County Forest 7-1, located in SE¼ sec. 7, T. 26 S., R. 13 W., and drilled to a total depth of 3,993 ft; and the WNS-Menasha 32-1, located in SW¼ sec. 32, T. 26 S., R. 13 W., and drilled to a total depth of 1,594 ft, were suspended pending further evaluation.

At Mist Gas Field, Nahama and Weagant Energy Corporation of Bakersfield, California, in partnership with Oregon Natural

Table 1. *Oil and gas permits and drilling activity in Oregon, 1993*

Permit no.	Operator, well, API number	Location	Status, depth(ft) TD=total depth PTD=proposed TD
456-R	Nahama and Weagant Adams 31-34-75 RD 36-009-00282-01	NE¼ sec. 34 T. 7 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 3,419.
472	Nahama and Weagant CC 41-33-75 36-009-00297	NE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Extended; PTD 2,850.
474	Nahama and Weagant LF 12A-33-75 36-009-00299	NW¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Completed, gas; TD 2,475.
476	Nahama and Weagant LF 12B-35-75 36-009-00301	NW¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Completed, gas; TD 3,727.
477	Nahama and Weagant LF 43-32-65 36-009-00302	SE¼ sec. 32 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD 1,909.
478	Nahama and Weagant LF 31-36-65 36-009-00303	NE¼ sec. 36 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD 3,987.
479	Nahama and Weagant CC 42-32-74 36-009-00304	NE¼ sec. 32 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD 1,700.
480	Nahama and Weagant CC 43-8-64 36-009-00305	SE¼ sec. 8 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD 2,150.
481	Nahama and Weagant CC 22B-19-65 36-009-00306	NW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD 2,940.
482	Nahama and Weagant CC 41-36-75 36-009-00307	NE¼ sec. 36 T. 7 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 1,792.
483	Nahama and Weagant CFW 41-35-75 36-009-00308	NE¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 3,331.
484	Nahama and Weagant CC 42-34-65 36-009-00309	NE¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD 3,150.
485	Carbon Energy Intl. JCLC Menasha 28-1 36-011-00025	SW¼ sec. 28 T. 26 S., R. 13 W. Coos County	Application; PTD 1,650.
486	Carbon Energy Intl. WNS Menasha 32-1 36-011-00026	SW¼ sec. 32 T. 26 S., R. 13 W. Coos County	Suspended; TD 1,594.
487	Carbon Energy Intl. Coos County Forest 7-1 36-011-00027	SE¼ sec. 7 T. 27 S., R. 13 W. Coos County	Suspended; TD 3,993.
488	Nahama and Weagant Adams 14-31-74 36-009-00310	SE¼ sec. 31 T. 7 N., R. 4 W. Columbia County	Permit issued; PTD 2,700.
489	Nahama and Weagant HNR 42-27-64 36-009-00311	NE¼ sec. 27 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD 2,500.
490	Nahama and Weagant HNR 24-22-64 36-009-00312	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Abandoned, dry hole; TD 2,553.
491	Nahama and Weagant HNR 31-21-64 36-009-00313	NE¼ sec. 21 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD 2,100.
492	Nahama and Weagant CFW 23-33-74 36-009-00314	NW¼ sec. 33 T. 7 N., R. 4 W. Columbia County	Permit issued; PTD 1,700.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1993 (continued)*

Permit no.	Operator, well, API number	Location	Status, depth(ft) TD=total depth PTD=proposed TD
493	Nahama and Weagant CC 24-19-65 and RD 36-009-00315/-315-01	SW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 3,044, RD 2,882.
494	Nahama and Weagant Hemeon 13-14-65 36-009-00316	SW¼ sec. 14 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD 2,800.
495	Nahama and Weagant Johnston 11-30-65 and RD 36-009-00317/-317-01	NW¼ sec. 30 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 2,794, RD 2,811.
496	Nahama and Weagant Libel 32-15-65 36-009-00318	NE¼ sec. 15 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD 2,835.
497	Nahama and Weagant LF 21-32-75 36-009-00319	NW¼ sec. 32 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD 2,500.
498	Carbon Energy Intl. Menasha Timber 16-1 36-011-00028	SW¼ sec. 16 T. 26 S., R. 13 W. Coos County	Application; PTD 2,650.
499	Carbon Energy Intl. Davis Cr. Menasha 32-2 36-011-00029	SE¼ sec. 32 T. 26 S., R. 13 W. Coos County	Application; PTD 1,800.

Table 2. *Canceled permits, 1993*

Permit no.	Operator, well, API number	Location	Date issued, canceled	Reason
455	Nahama and Weagant CC 14-32-75 36-009-00281	SW¼ sec. 32 T. 7 N., R. 5 W. Columbia County	5-28-91, 5-29-93	Canceled; expired.
473	Nahama and Weagant CC 22B-35-75 36-009-00298	NW¼ sec. 35 T. 7 N., R. 5 W. Columbia County	12-21-92, 12-21-93	Canceled; expired.
475	Nahama and Weagant Adams 12-31-74 36-009-00300	NW¼ sec. 31 T. 7 N., R. 56 W. Columbia County	12-21-92, 12-21-93	Canceled; expired.

Gas Development of Portland, Oregon, operated all the wells during the year. This included eleven wells and three redrills. Of these, five were successful gas wells: CC 22B-19-65, located in NW¼ sec. 19, T. 6 N., R. 5 W., and drilled to a total depth of 2,940 ft; LF 12A-33-75, located in NW¼ sec. 33, T. 7 N., R. 5 W., and drilled to a total depth of 2,475 ft; LF 12B-35-75, located in NW¼ sec. 35, T. 7 N., R. 5 W., and drilled to a total depth of 3,727 ft; LF 31-36-65, located in NE¼ sec. 36, T. 6 N., R. 5 W., and drilled to a total depth of 3,987 ft; LF 43-32-65, located in SE¼ sec. 32, T. 6 N., R. 5 W., and drilled to a total depth of 1,909 ft. Six wells and three redrills were dry holes and were plugged and abandoned: CFW 41-35-75, located in NE¼ sec. 35, T. 7 N., R. 5 W., drilled to a total depth of 3,331 ft; CC 24-19-65 and RD, located in SW¼ sec. 19, T. 6 N., R. 5 W., drilled to a total depth of 3,044 ft and redrilled to a total depth of 2,882 ft; CC 41-36-75, located in NE¼ sec. 36, T. 7 N., R. 5 W., drilled to a total depth of 1,792 ft; HNR 24-22-64, located in SW¼ sec. 22, T. 6 N., R. 4 W., and drilled to a total depth of 2,553 ft; Johnston 11-30-65 and RD, located in NW¼ sec. 30, T. 6 N., R. 5 W., drilled to a total depth of 2,794 ft and redrilled to a total depth of 2,811 ft;

Wellhead at the LF 31-36-65 well, which was operated by Nahama and Weagant and completed as a gas producer during 1993 at the Mist Gas Field .

Libel 32-15-65, located in NE¼ sec. 15, T. 6 W., R. 5 W., drilled to a total depth of 2,835 ft; and Adams 31-34-75 RD, a redrill of a previously suspended well located in NE¼ sec. 34, T. 7 N., R. 5 W., which reached a total depth of 3,419 ft.

Total drilling footage for the year was 44,565 ft, which is a significant increase from the 18,102 ft drilled during 1992. Average depth per well was 2,785 ft, which is a greater depth than the 2,586 ft per well drilled during 1992.

During 1993, DOGAMI issued 21 permits to drill (Table 1), while three permits were canceled (Table 2).

DISCOVERIES AND GAS PRODUCTION

Mist Gas Field in Columbia County saw five new successful gas wells, an increase from the two gas wells drilled in 1992. Nahama and Weagant Energy is the operator of the new producers that include CC 22B-19-65, the westernmost producer in the field; LF 12A-33-75, the northernmost producer in the field; and the LF 12B-35-75, LF 31-36-75 and LF 43-32-65 wells, all of which are more centrally located in the field. Nahama and Weagant operated 21 gas wells during 1993. At the end of the year, the field contained 18 gas producers; in addition, six wells were awaiting pipeline connection.

Gas production for the year totaled 3.5 Bcf, an increase from the 2.5 Bcf produced during 1992. The cumulative field production as of the end of 1993 was 49.8 Bcf. The total value of the gas produced for the year was about $7.1 million, a significant increase from the $3.4 million during 1992. Gas prices ranged from about 16¢ to 25¢ per therm, which is an increase from the 13¢ to 16¢ per therm last year. Cumulatively, the total value of gas produced since the Mist Gas Field was discovered in 1979 is about $104 million.

GAS STORAGE

The Mist Natural Gas Storage Project remained fully operational during 1993. The gas storage project has nine injection-withdrawal service wells, five in the Bruer Pool and four in the Flora Pool, and thirteen observation-monitor wells. The pools have a combined storage capacity of 10 Bcf of gas. This allows for the cycling of about 6 Bcf of gas in the reservoirs at pressures between approximately 400 and 1,000 psi and will provide for an annual delivery of 1 million therms per day for 100 days. During 1993, about 6,264,736,000 cubic feet of gas was injected, and 6,302,467,000 cubic feet was withdrawn at the Mist gas storage project.

OTHER ACTIVITIES

DOGAMI completed a five-year study of the oil and gas potential of the Tyee Basin during 1993. The Tyee Basin is located in Douglas and Coos Counties in the southern Coast Range. The study, which was funded by landowners in the study area and by county, state, and federal agencies, is an investigation of source rock, stratigraphy, and structural framework for those characteristics that are needed to generate and trap oil and gas. As results of this investigation, DOGAMI has published a number of maps and reports that present a revised understanding of the geologic framework of the Tyee Basin (see references below). A final oil and gas study summary and revised geologic map of the Tyee Basin will be published in the near future.

DOGAMI and the Northwest Petroleum Association (NWPA) sponsored a series of meetings at which the U.S. Geological Survey and Minerals Management Service discussed the ongoing national assessment of undiscovered oil and gas reserves. The assessment is using a methodology in which oil and gas plays are

This former drill site, where ARCO Oil and Gas Company had drilled the Hamlin 33-17-65 well and abandoned the operation during 1990, was reclaimed for use as a cattle stockyard.

evaluated for their future potential reserves. A draft report is expected to be released during 1994. Individuals who are interested in oil and gas resources in the Pacific Northwest should contact DOGAMI for details.

The NWPA remained active during the year. At its regular monthly meetings, speakers gave talks related to energy matters in the Pacific Northwest. The 1993 symposium was held in Bend on "Earth Resources and the Pacific Northwest", and plans are now underway for the 1994 symposium. For information, contact the NWPA, P.O. Box 6679, Portland, OR 97228.

During the summer of 1993, the Mist Gas Field, which was discovered in 1979 and has 18 productive wells and an underground natural gas storage facility, reached $100 million in revenues from natural gas production. In recognition of this milestone, DOGAMI, Northwest Natural Gas, Oregon Natural Gas Development Corp., and Nahama and Weagant Energy held a celebration at the field. Mist Gas Field is a successful endeavor between private industry, government, and public organizations in which landowner rights and the environment are protected, while the natural gas generates tax and royalty revenues and provides other direct benefits for the residents of Columbia County.

Nahama and Weagant Energy and Oregon Natural Gas Development began work on the installation of a nitrogen rejection unit at the Mist Gas Field during 1993. The unit will remove nitrogen from the methane gas produced at the field, and the process will result in increased production from those wells that have high nitrogen levels.

Pacific Gas Transmission Company will soon complete construction of a 42-in. natural gas pipeline that stretches over 805 mi from Canada to California, crossing Oregon approximately parallel to State Highway 97, through Biggs, Bend, and Klamath Falls. The $1.7-billion project will increase supply capacity by approximately 900 million cubic feet per day, about 16 percent of it for the Oregon market. Statistics show that, during the last ten years, Oregon's consumption of natural gas has more than doubled. Much of the pipeline crosses lands managed by the U.S. Bureau of Land Management (BLM), so the BLM Prineville District has taken the lead in ensuring minimal environmental impact and proper restoration of the land disturbed by the pipeline and its construction.

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Tri-State Agreement on Mining begins implementation

by David K. Norman, Washington Division of Geology and Earth Resources, P.O. Box 47007, Olympia, Washington 98504-7007, and Allen H. Throop, Oregon Department of Geology and Mineral Industries, Mined Land Reclamation Program, 1536 Queen Avenue SE, Albany, Oregon 97321

This article was originally written by David K. Norman and appeared in *Washington Geology*, volume 21, number 3 (November 1993), page 19-21. It has been modified by Allen H. Throop and is reprinted here with permission. *—ed.*

INTRODUCTION

Officials of Idaho, Oregon, and Washington signed an agreement in 1993 to share technical information about mine regulation and training opportunities, the Tri-State Agreement on Mining. In a cooperative effort to learn from each other and avoid reinventing the wheel, the three states have obtained $225,000 from the U.S. Environmental Protection Agency to encourage the sharing of information, resources, and experience. Ultimately this agreement will lead to wiser resource development and protection.

Mine regulators in the three states now face more complex issues than in the past, and in order to be effective, they must keep abreast of the latest technology. Each state has a small staff working with mine permitting. By working together, the states are learning from each other. This article summarizes some of the completed and anticipated projects under the grant.

A team of regulators, represented mainly by Allen Throop (Oregon), Bruce Schuld (Idaho), and David K. Norman (Washington), visited several mines and proposed mine sites in Washington, British Columbia, Oregon, and Idaho. The emphasis of the team's investigation was on water quality, chemical processing and control, and reclamation techniques. A summary of some of the site visits is presented below.

Figure 1. Road reclamation in progress at the Cannon Mine, Washington. These slopes have been reshaped to match the local natural slopes. Seeding is done at first planting season after reshaping to minimize erosion.

Cannon Mine, Washington, Asamera Minerals, Inc.

During their visits in Washington, the team members observed the underground operations, tailings impoundments, and surface reclamation at the Cannon gold mine in Wenatchee. The mine, operated by Asamera Minerals, Inc., uses a flotation method to concentrate gold. Concentrated ore is shipped to Japan for smelting. Asamera is nearing completion of mining and has finished earth work on some of the upper roads, drainages, and pits (Figure 1).

Stopes are backfilled with concrete made with locally mined sand and gravel, and ore is then removed from the adjacent stope. This method allows for more recovery of ore and eliminates subsidence.

Since they are too finely ground to be used as backfill, the tailings must be handled in an impoundment that was constructed across a valley immediately upstream from the mine and mill. Natural clays with a very low permeability act as a liner beneath the impoundment; no synthetic liner was used. Four wells in the valley below the impoundment were installed to detect any leakage. An additional well used to determine the background quality of water entering the tailings impoundment is upstream of the facility. The elevation of the well bottom is higher than the final maximum elevation of tailings.

Crown Jewel Project, Washington, Battle Mountain Gold

Battle Mountain Gold (BMG) proposes to develop an open-pit gold mine on Buckhorn Mountain near Chesaw in north-central Washington to recover gold from a skarn deposit. BMG plans to treat the ore with a vat cyanide leach process that uses a carbon recovery system and a sulfur dioxide (SO_2) cyanide destruction process patented by International Nickel Company. The proposal also calls for a tailings impoundment lined with clays compacted to very low permeability (10^{-6} cm/s or less) below synthetic geomembrane liners. Nine ground-water monitoring wells and 17 surface-water monitoring sites and water from four existing adits are being used to gather baseline data for the environmental impact statement that is being prepared.

Nickel Plate Mine, British Columbia, Homestake Mining Co.

The tri-state group visited the Nickel Plate Mine in southern British Columbia because it is geologically similar to the proposed Crown Jewel Project. The ore processing techniques are similar to those proposed for the Crown Jewel, as is the INCO SO_2 cyanide destruction method. However, due to the nature of the ore deposit at Nickel Plate, several open pits have been mined rather than one large pit as proposed for Crown Jewel. Homestake backfills mined-out pits with waste rock, leaving only the last pit as a series of benches and highwalls.

Final waste-rock dump slopes at the Nickel Plate Mine are generally 3 ft horizontal for each 1 ft vertical (3:1), with a maximum height of 80 ft between terraces or breaks in slope on the dumps (Figure 2). Topsoil is placed on the 3:1 slopes to support revegetation. Clays and silts are salvaged from nearby glacial till to supplement the thin soils. Crested wheat, rye, and clovers are the first ground-cover plantings used to stabilize the soils on dump slopes. Native plant species will be emphasized as revegetation proceeds.

The tailings impoundment is unlined. Leakage through the underlying glacial till has been a problem. Homestake installed collection piping and trenches about 3 ft below the level of the adjacent Canty Creek and between the creek and the tailings impoundment. The system appears to be effectively retrieving the low levels of escaped cyanide, which is then pumped back to the tailings impoundment.

NERCO DeLamar had also begun a program to improve water quality from the so-called "16 level adit," from which acidic water with high metal content has been draining for many years. The low pH and metals were degrading the water quality of Jordan Creek. As a short-term solution, discharge from the adit is now being pumped to the tailings pond, and the effect of the pumping on the water quality in the tailings impoundment is being studied. Possible long-term solutions include blocking the adit and flooding the old workings. This would prevent oxygen from reaching the system, which in turn would stop acid generation. Another approach would be to eliminate water from the underground workings.

To reduce handling costs and to improve reclamation, waste rock is being used to backfill some mined-out areas. Other reclamation completed at the site includes converting a clay borrow pit and numerous storm-water control ponds to wetlands.

Figure 2. Waste dumps at Homestake's Nickel Plate Mine in British Columbia is being reshaped to relatively flat (3:1) slopes, which are much more successful in revegetation efforts than steeper slopes.

Central Idaho

Because it is on patented claim land, the Coeur d'Alene Mining Co. Thunder Mountain gold mine, located at an elevation of about 8,000 ft, was excluded from the surrounding Frank Church River of No Return Wilderness Area. The site had been mined for gold in the mid-1980s (Figure 3). The company's earth-moving phase of reclamation, which was completed by 1991, was imaginative, and appropriately it received awards for innovative work. Coeur d'Alene reshaped most of the open pits, the cyanide heap leach processing area, and the waste dumps. Revegetation is slowly becoming established. Lodgepole pines are doing well despite two years of drought. Common yarrow is doing extremely well in one area in spite of heavy grazing by elk. Nonnative grasses are doing fairly well, although the disturbed areas are not yet fully covered. Ultimately, the area will return to a lodgepole pine forest.

DeLamar Mine, Idaho, Kinross Gold, Inc.

Representatives from all three states also visited the Kinross Gold, Inc., DeLamar gold and silver mine in southwest Idaho. This mine, which consists of several pits, uses an agitated cyanide leach process to recover gold and silver. The high cyanide content in the tailings impoundment represented hazards to waterfowl. In response to this, the former operator, NERCO DeLamar, constructed the first AVR (Acidification-Volatilization-Reneutralization) system in the U.S. at the DeLamar Mine. The plant is recovering 183 lb/hr of cyanide or over 90 percent of the cyanide in the tailings solutions, which is reused rather than destroyed.

Elsewhere on the site, acidic water draining from waste rock into Sullivan Gulch (a quarter of a mile southeast of the DeLamar Mine) is now being pumped to the tailings impoundment as a short-term measure to control acid-rock drainage problems. Proposed long-term solutions include capping the waste to prevent infiltration of water or processing the waste rock through the mill.

Figure 3. Sunnyside pit at Coeur d'Alene Thunder Mountain Mine at the end of the mining operation, before reclamation began. Completed reclamation is shown in Figure 4.

This site shows the contrast between the angle-of-repose waste dumps (with slopes approximately 1.5:1) and dumps whose slopes are at 3:1 or flatter. No vegetation was growing on the steep waste-rock dump slopes, which were failing, while gentler slopes were sustaining vegetation and appeared stable. An unsuccessful attempt was made to cover the steep dump with coarse rock to make it similar to a talus slope.

Detoxified spent ore was removed from the cyanide heap leach pad and used to backfill pits and reshape them to approximate the surrounding topography (Figure 4). Upon completion of the mining, all buildings were removed, and the processing area as well as most of the pits and dumps were covered with growth media. Some coarse rock and logs were spread for habitat diversity and microclimate enhancement.

Around the processing area, 13 monitoring wells were drilled, three updrainage and ten downdrainage. Numerous surface-water monitoring sites were established. No cyanide has been detected in the ground water. Only one apparently anomalous surface-water sample indicated that cyanide was present, but retesting failed to locate any cyanide in the surface or ground water.

Figure 4. Reclaimed Sunnyside pit at Coeur d'Alene Thunder Mountain Mine. Pit walls have been worked into sinuous contours and rolling topography. Newly planted vegetation has endured two years of drought. Lodgepole pines, which were severely stressed, show excellent recovery and growth after heavy winter snows and a wet summer. Grasses, although still sparse, continue to spread and provide seeds.

Successes at this site include the ponds created by shaping the topography to trap snow drifts and the notable lack of highwalls in reclaimed open pits. Elk and deer are already grazing on this site.

Not far from Thunder Mountain are two other gold mines: the MinVen Stibnite Mine and the Hecla Mining Co. Yellow Pine Mine. Hecla has completed mining and begun reclamation, sloping the waste rock dumps to about 3:1 to 4:1. Vegetation was doing well, and slopes appeared to be stable. The open pit has been mostly recontoured and revegetated. Because the neighboring MinVen mine is still operating, Hecla can do no further reclamation. The cyanide heap leach pad and ponds remain to be reclaimed.

Hecla is applying state-of-the-art bioneutralization techniques to destroy cyanide and nitrate in the heap leach pad. This process involves the cultivation and introduction of microorganisms that thrive on free cyanide and on most of the cyanide compounds found in the heap leach chemical environment and that break down the cyanide.

Coeur d'Alene, Hecla, and NERCO all won awards for their outstanding reclamation efforts at the mines just described, for efforts that went beyond the Idaho requirements. The awards were given last summer by the Idaho Mining Advisory Committee and presented by Idaho Governor Cecil Andrus at a luncheon held to honor the progressive mining companies.

Other interstate projects

The Washington Division of Geology and Earth Resources is preparing a bibliography of information about reclamation of metal mines. A rough draft has been sent to interested parties for review.

Oregon, Washington, and Idaho agency personnel reviewed the Newmont Mining Co. baseline data collection plan for the company's Grassy Mountain, Oregon, proposal. The team also reviewed the Formosa Exploration, Inc., Silver Butte Mine, also in Oregon, and the cleanup efforts of the operation's impact on Middle Creek.

Oregon and Washington representatives, including representatives from the Fish and Wildlife Departments and private industry, visited gravel pits in southwestern Washington to exchange ideas about using such areas as off-stream resting areas for anadromous fish.

Other anticipated activities within the framework of the Tri-State Agreement on Mining include:

- Conferences to discuss common issues in acid rock drainage characterization;
- Avoidance and rapid, inexpensive methods of stream characterization;
- Assessment and evaluation of blasting techniques for reclamation;
- Compilation of best management practices manuals for Washington and Oregon, based on a similar document used in Idaho;
- Publishing articles summarizing state-of-the-art reclamation practices in hard rock mining. □

Mineral information available in new directory

The U.S. Bureau of Mines has published a new *Directory of Mineral-Related Organizations* that provides information on minerals, mineral issues, and technical assistance. The directory includes federal and state government agencies and national, regional, and state associations concerned with the mineral, metal, and material sectors of the economy.

Price of the new directory is $8. It is available under GPO Stock No. 024-004-02271-0 from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402, phone (202) 783-3238. A little closer for Oregonians may be the GPO Book Store in Portland, which also has the book available. The address is 1305 SW First Avenue, Portland, OR 97201-5801, phone (503) 221-6217. □

Summary of 1994 activities, Oregon Department of Geology and Mineral Industries

The mission of the Oregon Department of Geology and Mineral Industries (DOGAMI) is to serve as the cost-effective centralized source of geologic information in Oregon for the public and for government. Its mission is also to serve as a cost-effective steward of mineral production with attention paid to environment, reclamation, conservation, and other engineering and technical issues.

With regard to geologic information, emphasis is placed on geologic mapping, cost-effective earthquake mitigation, geologic hazards, and mineral resources. With regard to mineral stewardship, authorities are in place for the exploration, production, and reclamation of oil, gas, geothermal, aggregate, and nonaggregate mineral resource activities. The emphasis in DOGAMI activities is placed on prevention of hazards and waste, benefits of long-range planning, and the efficiency of using land and mineral knowledge in policy decision making in government and the private sector.

Acronyms are explained at the bottom of this page.

Focus	Activity/project	Contact persons	Description and partners
Geologic hazards (Delineation to facilitate cost-effective mitigation)	Earthquake hazard inventory	Ian Madin Matthew Mabey Mei Mei Wang (503) 731-4100	Provides ground-response maps and models for urban and coastal areas, seismic-velocity data from cooperative bore holes, leadership or technical assistance for earthquake scenarios, paleoseismology, active faults, workshops, earthquake response training and planning, and policy-centered mitigation. Partners and cooperators include USGS, METRO, PSU, ODOT, SSPAC, FEMA, OEM, and the Department of Higher Education.
	Coastal erosion	George Priest Dennis Olmstead (503) 731-4100	Continues analysis of coastal erosion and tsunami potential in a central-coast pilot project, using geologic analysis and historic shoreline data; evaluates results, integrates geologic considerations into a model, and cooperates in outreach efforts to develop mitigative strategies. Partners and cooperators include LCDC, OCZMA, OSU, and local government. Activity includes membership on Coastal Natural Hazard Policy Workshop Group and Technical Advisory Committee.
Regulation of extraction of geologic resources (Environmentally sound and safe exploration and production, followed by second beneficial land use)	Surface mined land reclamation	Gary Lynch Allen Throop Frank Schnitzer Peter Wampler (503) 967-2039	Provides for safe and environmentally sound surface mining, leading to beneficial second use, in cooperation with other agencies, including local government. Authority includes aggregate and metal mines, possible cyanide heap leach mines, and exploration. Cooperation with local government is provided in rules and State Agency Coordination Agreement. Partnerships with federal agencies are delineated in memoranda of understanding.
	Oil, gas, and geothermal resources	Dennis Olmstead Dan Wermiel (503) 731-4100	Provides for conservation of resource, protection of environment, safety, and second beneficial use of land plus equitable distribution of revenues where necessary. Authority includes exploration, drilling, production, and reclamation. Governing Board functions as Oil and Gas Commission. Partnerships with federal agencies are defined in memoranda of understanding.
Prioritized geologic mapping and data collection (Multidisciplinary geologic data for a broad variety of societal needs)	Northwest Oregon	George Priest (503) 731-4100	Guides in cooperation with Advisory Committee and prepares geologic mapping in northwestern Oregon with emphasis on quadrangles in the Portland area and East Vancouver sheet and on facilitating or attracting mapping efforts by cooperators in support of agency objectives.
	Southwest Oregon	Tom Wiley Frank Hladky Jerry Black (503) 476-2496	Conducts in cooperation with Advisory Committee mapping on a cooperative basis in the east-central Medford 1°x 2° sheet and the Roseburg 1°x 2° sheet. Partners and cooperators include UO and USGS.
	Eastern Oregon	Mark Ferns (503) 523-3133	Conducts in cooperation with Advisory Committee geologic quadrangle mapping of the Bend sheet and other areas for the purposes of enhancing local economy, facilitating cost-effective use of land resources, and delineating geologic hazards. Cooperators and partners include USGS, PSU, and the private sector. Current emphasis is on completion of 7½′ quadrangles leading to completion of 1:100,000-scale final map products.

Acronyms:

BLM	U.S. Bureau of Land Management	OCZMA	Oregon Coastal Zone Management Association
BPA	Bonneville Power Administration	ODOT	Oregon Department of Transportation
DSL	Division of State Lands	OEM	Oregon Emergency Management
FEMA	Federal Emergency Management Administration	OPAC	Ocean Policy Advisory Council
GIS	Geographic Information System	PSU	Portland State University
LCDC	Land Conservation and Development Commission	SWMG	Strategic Water Management Group
METRO	Metropolitan Service District	UO	University of Oregon
MILO	Mineral Information Layer for Oregon	USFS	USDA Forest Service
MLR	Mined Land Reclamation	USGS	U.S. Geological Survey

Summary of 1994 activities, Oregon Department of Geology and Mineral Industries (continued)

Focus	Activity/project	Contact persons	Description and partners
Public service and information (Getting the information out of government and to the public)	The Nature of Oregon Information Center	Don Haines (503) 731-4444	Serves as a multidisciplinary, multi-agency outlet for natural resource agency information. The center is located in the state office building in Portland. Emphasis is on distribution of information to the public in the Portland metropolitan area for the purposes of general public education, tourism enhancement, and public service. Cooperators include state natural-resource agencies, the Oregon Productivity Fund, and USGS.
	Oregon Geology, publications, library	Beverly Vogt Paul Staub Mark Neuhaus Klaus Neuendorf (503) 731-4100; Janet Durflinger Baker City Office (503) 523-3133; Kathleen Murphy Grants Pass Office (503) 476-2496	Serves to release a broad array of agency and cooperative geologic information to the broad public in a timely and cost-effective manner with publications, a subscription-based periodical, and a technical library coordinated with the State Library System.
Economic geology (Facilitating economic diversification, primarily in rural Oregon)	Mineral database for GIS, planning and policy guidance (MILO)	Frank Hladky (503) 476-2496	Provides a PC-oriented database of 8,500 mines, prospects, and occurrences based on all USGS, BLM, and MLR data and agency unpublished data bases and designed for dBase 3+ retrieval utilizing a variety of fields including location. Partners include USGS, BLM, and USFS. Applications include local planning, basin planning, and resource overviews. This database constitutes the state "mineral layer" for GIS applications.
	Industrial minerals and area inventories	Ron Geitgey Bob Whelan (503) 731-4100	Conducts statewide assessments and regional evaluations of industrial minerals for purposes of rural diversification. Current emphasis is on area studies for clients such as Warm Springs Indian Reservation, DSL, and other agencies with land holdings. The possible need for targeted aggregate studies is being monitored. Increasing emphasis is on minerals economics and cost-effective decision-making in the policy arena.
	Geologic energy	George Priest Jerry Black (503) 731-4100	Serves as source of geotechnical advice for geothermal energy and inventory resources in Cascades and southeastern Oregon. Continues natural-gas assessment of the southern Coast Range (Tyee Basin) with emphasis on resource targeting through reconnaissance mapping and transect development. Cooperators include BPA, landholders, DSL, Oregon Lottery, UO, USFS, and BLM.
Selected planning (Making sure geology, minerals, and hazards are realistically addressed by policy makers)	Water	Dan Wermiel (503) 731-4100	Links agency geologic mapping and data with state water-quality and water-quantity planning efforts through referrals, delivery of publications, and strategic technical advice, particularly to SWMG members.
	Facility siting	Dan Wermiel and selected hazards staff (503) 731-4100	Provides geotechnical site reviews for highest priority selected facilities such as power plants, dams, and essential or critical facilities with emphasis on geologic-hazard consideration.
	Local government	Dennis Olmstead Dan Wermiel (503) 731-4100; also, technical assistance by regional geologists at Baker City (503) 523-3133, Grants Pass (503) 476-2496, and Portland (503) 731-4100	Prioritizes and oversees agency planning involvement. Links planning efforts to necessary agency databases with emphasis on periodic review and plan amendments. Input is largely in areas of mineral potential and geologic hazards. Increasing emphasis is being placed on seismic information (ground response) and how it is to be utilized in relatively high risk areas in planning.
	Offshore coordination	Dennis Olmstead (503) 731-4100	Contributes to state offshore policy development through participation in OPAC and related policy and technical working groups. □

Tsunami — "Big wave in the harbor"

From an article by Klaus Jacob in Die Zeit, *overseas edition, no. 30 (July 30), 1993, p. 13, excerpted by Klaus K. Neuendorf. Additional information from Oregon Department of Geology and Mineral Industries.*

The most recent major tsunami event struck Japan not long ago. In late evening of July 12, 1993, a strong earthquake had just finished shaking the buildings on the small Japanese island of Okushiri, and many of them had collapsed. Seismologists later determined the earthquake magnitude to have been M_L 7.8 (Richter scale). As soon as the shaking subsided, fishermen ran to the harbor to look after their boats, the basis of their subsistence. It was only then that the real catastrophe hit them: A wave 8 m (26 ft) high crashed into the harbor and wiped out men and boats alike. A tsunami had been triggered by the earthquake and had rolled over Japan's coasts. A preliminary estimate counted at least 200 people killed by the combination of earthquake and wave.

The Japanese have always lived on a restless piece of the Earth's crust and are used to the hazards of volcanic eruptions, earthquakes—and tsunamis. However, these giant breakers, which can reach heights of up to 30 m (100 ft), threaten not only Japan but all countries that have sea coasts, even around the Mediterranean. Indeed, scientists suspect that it was a tsunami related to the explosion of the Santorini volcano that extinguished the Minoan civilization around 1500 B.C. And as recently as 1992, for example, towns in Nicaragua and Indonesia were devastated by 10- to 20-m (30- to 60-ft) tsunami waves.

We are not completely helpless against these forces of nature any more. As early as 1948, the first tsunami-alert service [the Pacific Tsunami Warning Center in Honolulu, Hawaii] began operations in the Pacific region, and others followed soon. When a strong earthquake is registered, the observers check to see whether their network's tidal gauges report any unusual water levels. If the sea level rises or falls more than normally, danger is imminent. Checking water levels is still an essential tool, because not every earthquake sets the sea in motion. A tsunami wave is generated only when the earthquake lifts the sea floor and pushes the water up as in a piston. If, on the other hand, two crustal blocks slide past each other in a horizontal motion, there is no danger. Thus, earthquakes along the infamous San Andreas fault in California leave the sea unruffled.

This fact was still unknown to pioneer seismologist T.A. Jagger more than half a century ago, when he—acting alone—warned the fishermen of Hawaii, after a strong earthquake in distant Kamchatka had set off a tsunami. In 1923, he was celebrated as a hero, because his alarm had saved lives and fishing vessels. After that early success, however, one false alarm followed another, when the seismometers in Jagger's observatory again and again registered strong motions.

In his day, Pioneer Jagger had to notify the fishermen himself whenever his indicators pointed toward high tides. Today, warning networks sound the alarm with all imaginable media involvement. Radio and television promptly go on the air with announcements. Thanks to modern electronics, everything clicks in a matter of just minutes: Data are delivered from the most remote seismograph and tidal gauging stations. Computers then calculate the epicenter and the magnitude of the earthquake. The path of the tsunami is determined, and the alert is passed on to the media.

During the tsunami of last July, everybody in Japan could watch on the screen at what time the tsunami would hit which coasts. Television programs displayed maps on which endangered coastal areas would be shown blinking red and yellow. Unfortunately, the warning came too late for the people on the island of Okushiri: They were too close to the epicenter of the tsunami-triggering earthquake, less than 100 km (60 mi) away. To cover that distance, the tsunami needed just a few minutes.

A tsunami can be as fast as a jet plane—and just as predictably on schedule. It is a curious phenomenon: Its speed depends entirely on the depth of the water. In a sea that is 4,000 m (13,000 ft) deep, it reaches a speed of 720 km (240 mi) per hour; if the sea floor drops to 6,000 m (20,000 ft), it speeds up to 870 km (260 mi) per hour. At the coast, it slows down abruptly. That is why it is easy for warning services to calculate the tsunami's path. In almost no time at all, a computer can deliver the time of arrival for all coastal areas if the sea-floor relief is stored in its memory and if it knows where the earthquake originated.

Another peculiarity of a tsunami is that it is hardly felt on the open sea. As wild as it may act on the coast, on the high seas it is rather tame. If one of its waves reaches a height of 2 m (7 ft) out on the ocean, it is already a big and dangerous tsunami. The wave does not approach as a big breaker: the sea level rises gradually, as if in slow motion, and falls again just as languidly. Ships' crews do not notice any of the spectacular action, because the crests of the waves are 100 km (60 mi) and more apart from each other. Such a wave resembles more the tidal heave caused by the moon rather than the choppiness caused by wind or storm.

Yet, in its inexorable advance, such an inconspicuous bulge of water, this sleeping giant, can cover thousands of miles and often crosses the entire Pacific Ocean. After the severe Alaska earthquake of 1964, a tsunami caused great damage as far away as California, at a distance of about 3,000 km (2,000 mi), where it arrived after 4 hours. One of the most devastating tsunamis arose in June of 1896, after an earthquake had shaken Japan. The tsunami ran toward the east, across the Pacific, overran Hawaii, crashed against the west coast of America, rebounded, and crossed the Pacific a second time, reaching coasts as far away as Australia and New Zealand. And it did all that in just one day.

It is only at the coast that a tsunami reveals its dramatic nature. Here, the wave rises to an impressive height and flings its entire force against the land. Few buildings can withstand the impact of such water masses. In April 1946, on an island in the Aleutians, even a lighthouse built of massive reinforced concrete and sitting 10 m (30 ft) above sea level collapsed. When the waters had dissipated, nothing was left of it but its foundation.

Bays are particularly endangered. Shores that converge at an acute angle focus the power of the entering water masses as a magnifying glass focuses light. The big breakers grow into massive, towering walls of water. All record flood levels have been measured in bays. That also means that a tsunami wreaks its worst havoc just where ports and cities are often located. That is why the Japanese have named the devastating flood "tsunami" — "big wave in the harbor."

In some bays, the giant waves may even reinforce each other. Hilo on Hawaii is known for this phenomenon: The first wave hits the coast, rebounds, and reinforces the second wave that arrives perhaps half an hour later. Each successive wave increases the water turbulence, so that often the maximum flood level is not reached until the third or fourth wave—at a time when in other places the all-clear signal has long been given.

In times past, a tsunami always hit people unawares. Thus it was, for example, on June 15, 1896, when a Japanese fishing village was celebrating a happy feast on the beach. The reveling company would not let its fun be spoiled by an earthquake that shook the ground slightly. The celebration continued even when, shortly after, the sea withdrew with soft, smacking noises much farther than at normal low tide. A wide stretch of beach went dry; fish were flopping on the moist sand. One hour later, the festivities came to a sudden end. The sea returned with a roar. A wave front seven stories high rushed in and buried the entire village.

Nowadays, modern technology turns the catastrophe of nature into a media spectacle. But early warnings often tempt curiosity seekers to drive to the coast in order to experience the show close up. In 1964, on the California beaches, the spectators were joined even by police sent to organize a quick evacuation. To look catastrophe in the eye is a gamble with death: over 100 people died on that occasion.

ADVICE TO OREGONIANS

The Oregon coast is vulnerable to tsunamis generated in two different ways: (1) by undersea earthquakes occurring thousands of miles away from Oregon, and (2) by undersea earthquakes occurring just offshore. Tsunamis generated by earthquakes occurring far away will take hours to reach the Oregon coast, leaving adequate time for official warning.

But tsunamis generated by earthquakes occurring just offshore may strike the coast within minutes of the earthquake, before official warning is possible. The only warning that may occur is the earthquake itself. Therefore, anyone living along the Oregon coast or visiting it should remember the following rules:

1. If you feel an earthquake when you are on the coast, protect yourself from the effects of the earthquake by dropping, covering, and holding on if you are indoors or by staying away from objects that may fall if you are outside—until the earthquake is over.

2. Then, even though you have been frightened or hurt by the earthquake, if you are in a low-lying area that could be affected by tsunamis, you must **immediately** move inland or to high ground. Tsunamis can travel upstream in coastal estuaries, with damaging waves extending farther inland than the immediate coast. Evacuate on foot if possible because of traffic jams and probable earthquake damage to roads and bridges. If you are unable to reach safe ground, the third floor or higher of a reinforced concrete building **may** offer protection, but such a building should be used only as a last resort. Do not wait for official warning, because the tsunami may strike before authorities have time to issue a warning or all power may be out, leaving warning systems nonfunctional.

3. Do not return to shore after the first wave. Additional waves may arrive up to several hours later, be higher, and go farther inland. People have died because they survived the first wave and thought it was safe to return to the shore. Wait until officials tell you the tsunami danger has passed.

4. If you are camping on or near the beach, you may have to immediately abandon your recreational vehicle or campsite to move inland or to high ground to save your life.

5. Never go to the beach to watch for a tsunami. Tsunamis move faster than a person can run. Also, incoming traffic hampers safe and timely evacuation of coastal areas.

6. If you see a sudden or unexpected rise or fall in coastal water, a tsunami may be approaching. Move inland or to high ground as quickly as possible.

7. Stay tuned to your radio, marine radio, NOAA weather radio, or television station during a tsunami emergency for instructions from authorities.

8. Make disaster plans with your family **before** a disaster occurs. Family members should be trained so they will know what to do on their own to protect themselves from an earthquake, where to go to survive a tsunami, and whom outside the disaster area to contact in case they are separated from each other by a disaster.

EDITOR'S NOTE

The Oregon Department of Geology and Mineral Industries, is preparing a brochure about tsunami hazards along the coast and what to do in case of an offshore earthquake and accompanying tsunami. The brochure will be available in April. For copies, contact any of the Department offices listed on the first inside page (page 26) of this issue.

Also: The current (March) issue of the *Smithsonian* has an interesting article on tsunamis on p.28-39. □

April is Earthquake Preparedness Month in Oregon

In the context of Earthquake Preparedness Month, between April 13 and 24, over 200 government jusrisdictions and agencies across Oregon will be participating in "QuakeEx94," a large-scale (subduction zone type) earthquake response simulation drill.

The Oregon Department of Geology and Mineral Industries has a number of geologic publications available that are related to earthquakes and earthquake hazard mitigation, as well as other literature that provides help in protecting against the dangers of earthquakes. Contact the Department's Nature of Oregon Information Center or the Baker City and Grants Pass field offices (addresses listed on page 26 of this issue. □

Map of radon zones now available

The Oregon Department of Geology and Mineral Industries (DOGAMI) and the State Health Division announce the availability of the Environmental Protection Agency's (EPA) publication entitled *Map of Radon Zones for Oregon*. The radon zone map, which identifies areas in Oregon that have the potential to produce elevated levels of radon, is included in the book.

The *Map of Radon Zones for Oregon*, which is designed to help national, state, and local governments and other organizations target radon activities and resources, was prepared by the EPA Office of Radiation and Indoor Air in conjunction with the U.S. Geological Survey and the Association of American State Geologists. It identifies, on a county-by-county basis, three zones having different radon potentials, ranging from low (less than 2 pCi/L) in zone 3, through moderate (between 2 and 4 pCi/L) in zone 2, to high (greater than 4 pCi/L) in zone 1. (The average concentration of radon in U.S. homes is between 1 and 2 pCi/L).

The radon potential study was nationwide in scope. Included in the publication is a map of radon zones for the whole United States. The publication discusses the national program and describes how radon develops, how it enters homes, and what methods were used to collect data for this study.

The publication then focuses on the Pacific Northwest and finally on Oregon, describing the geologic provinces of Oregon and discussing which areas have greatest potential for radon problems. Added as an appendix are two 1993 information circulars produced by the Oregon Health Division: (1) "The Radon Measurement Guide Including a Listing of Northwest Radon Measurement Companies Servicing Oregon," and (2) "Radon Levels and Radon Abatement Projects in Oregon Homes Listed by Zip Code and by County."

The EPA publication is a generalized assessment of Oregon's geologic radon potential, and the data cannot be applied to individual homes. Rather, it presents a generalized description of causes of radon contamination in homes and identifies areas of highest potential. As EPA officials state, "All homes should be tested, regardless of zone designation."

Copies of the EPA *Map of Radon Zones for Oregon* are available for purchase for $6 from the Nature of Oregon Information Center, Ste. 177, 800 NE Oregon #28, Portland, OR 97232, phone 503-731-4444; and from DOGAMI's field offices in Baker City (1831 First Street, Baker City, OR 97814, phone 503-523-3133) and Grants Pass (5375 Monument Drive, Grants Pass, OR 97526, phone 503-476-2496). □

THESIS ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that in our opinion are of general interest to our readers.

Active faults and earthquake ground motions in Oregon, by Silvio K. Pezzopane (Ph.D., University of Oregon, 1993), 208 pages.

Aerial photo interpretations and geologic field investigations in southern and central Oregon, combined with previous fault and seismicity studies nearby, indicate that late Pleistocene and Holocene fault activity is concentrated along four zones stretching northward into the Cascade volcanic arc and across the northwestern Basin and Range Province. Placed in a regional context, these active fault zones serve to separate Western Oregon from "stable" North America. Regional geodetic measurements, historic earthquake moment tensors, and the orientations and slip rates of faults that cross Oregon are the basis for constructing a kinematic model which reveals that the active faults accommodate overall motion in a direction ~N. 60° W. ± 25° at a rate between ~2 and 12 mm yr^{-1}. The model indicates that this proposed shear zone through Oregon can account for as much as 10 percent to 20 percent of the total Pacific-North American transform motion and almost all of the lateral component of Juan de Fuca Plate motion relative to the North America Plate.

The kinematic model of faulting, together with data describing the locations, lengths, and slip rates of late Quaternary and Holocene faults, are the bases for constructing predictive maps of earthquake ground motions, that will help to understand better the seismic hazards in Oregon. Potential earthquakes are hypothesized to occur along eleven major source zones, which include the Cascadia subduction zone, the subducting Juan de Fuca Plate, and nine zones of onshore and offshore crustal faults. Empirical relationships and the active fault data are used to estimate the magnitudes and recurrence intervals of hypothetical earthquakes. This information is encoded as map elements in a Geographical Information System (GIS), which is used to apply earthquake attenuation relations and to establish contours of peak horizontal ground acceleration and velocity across Oregon. A regional map of surficial geology is used to improve predictions of site response by accounting for potential seismic amplification at sites underlain by soft young sediments. All data are stored as GIS database layers that are combined with population density and various algorithms to produce maps of seismic ground motion, duration of shaking, probability of exceeding a damaging level of shaking, and seismic risk. Results indicate that, by area, as much as one-half of Oregon can expect peak ground accelerations to exceed 0.2 g at the 5-percent probability level in a 100-yr interval. As much as 80 percent of the Oregon population resides in areas that can experience strong ground motions (>0.2 g) and long durations of shaking (>60 s).

Prediction of displacements due to liquefaction-induced lateral spreading, by Matthew A. Mabey (Ph.D., Brigham Young University, 1992), 133 p.

The magnitude of ground displacements due to liquefaction-induced lateral spreads can be realistically modeled. This model can be based on readily measured parameters using the Newmark technique and simulated or recorded ground motions. This estimation is simple enough to be economically applied to predictive maps of ground displacement and accurate enough to be applied to site-specific studies. □

DOGAMI PUBLICATIONS

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two open-file reports that are not printed in multiple copies and are not for sale but limited to library access. These reports are available for inspection in the library of the Portland office of the DOGAMI (see address on page 26 of this issue). Photocopies may be obtained at cost. For copy services, contact Kinko's at 1605 NE 7th Avenue, Portland, OR 97232, phone (503) 284-2129.

Released January 28, 1994:
Preliminary geologic map of the Sourdough Spring quadrangle, Malheur County, Oregon, by M.L. Cummings. Released as Open-File Report O–93–11.

This map is part of the cooperative effort by DOGAMI, the U.S. Geological Survey, and Portland State University to map the west half of the Boise 1° x 2° sheet and has been released as supplementary map to the Vale 30′ x 60′ map published by DOGAMI as part of map GMS–79. The hand-colored map (scale 1:24,000) is accompanied by a 10-page explanatory text.

Released March 8, 1994:
Landslide and erosion hazards of the Depoe Bay area, Lincoln County, Oregon, by G.R. Priest. I. Saul, and J. Diebenow. This report was produced at the request of the City of Depoe Bay and has been released as Open-File Report O–94–3 for library access only. It includes a 23-page text and three hazard maps, with hazards plotted on aerial photos in which 1 in. equals 400 ft.

The report chiefly outlines chronic hazards of mass movement (unstable slopes) and sea-cliff erosion identified by investigations conducted during 1991–1993 and supported by the Federal Emergency Management Administration (FEMA) and the Oregon Department of Land Conservation and Development (DLCD) under the auspices of the National Oceanographic and Atmospheric Administration (NOAA). These investigations focused on the 31-mi stretch of coast from Cascade Head on the north to Seal Rock on the south.

An overview of catastrophic earthquake hazards is also included in the text, but these hazards are not mapped. The techniques for mapping earthquake hazard areas are being developed for an ongoing pilot study of the Siletz Bay area.

Open-File Report O–94–3 is preliminary and encompasses the city limits of Depoe Bay and adjacent lands. The final report will cover chronic hazards of the entire 31-mi study area and catastrophic hazards of the Siletz Bay area. □

MLR launches *Reclamation News*

The Mined Land Reclamation Program of the Oregon Department of Geology and Mineral Industries (DOGAMI-MLR) has published its first annual newsletter, *Reclamation News*.

The purpose of the newsletter is first of all to establish better communications between DOGAMI-MLR and those who hold mining permits. DOGAMI-MLR views *Reclamation News* as an informal way to convey information to operators, such as new reclamation strategies and techniques, advice on operating procedures that make reclamation easier and more cost effective, the names of the annual award recipients, and changes in Oregon's reclamation statutes.

As the *Reclamation News* states editorially: "DOGAMI-MLR's task is overseeing reclamation for the State of Oregon. The only way to make that job feasible is to provide technical assistance so that miners can accomplish effective reclamation themselves."

Questions, suggestions, and comments are invited. They sould be sent to Reclamation News, DOGAMI-MLR, 1536 Queen Ave. SE, Albany, OR 97321. □

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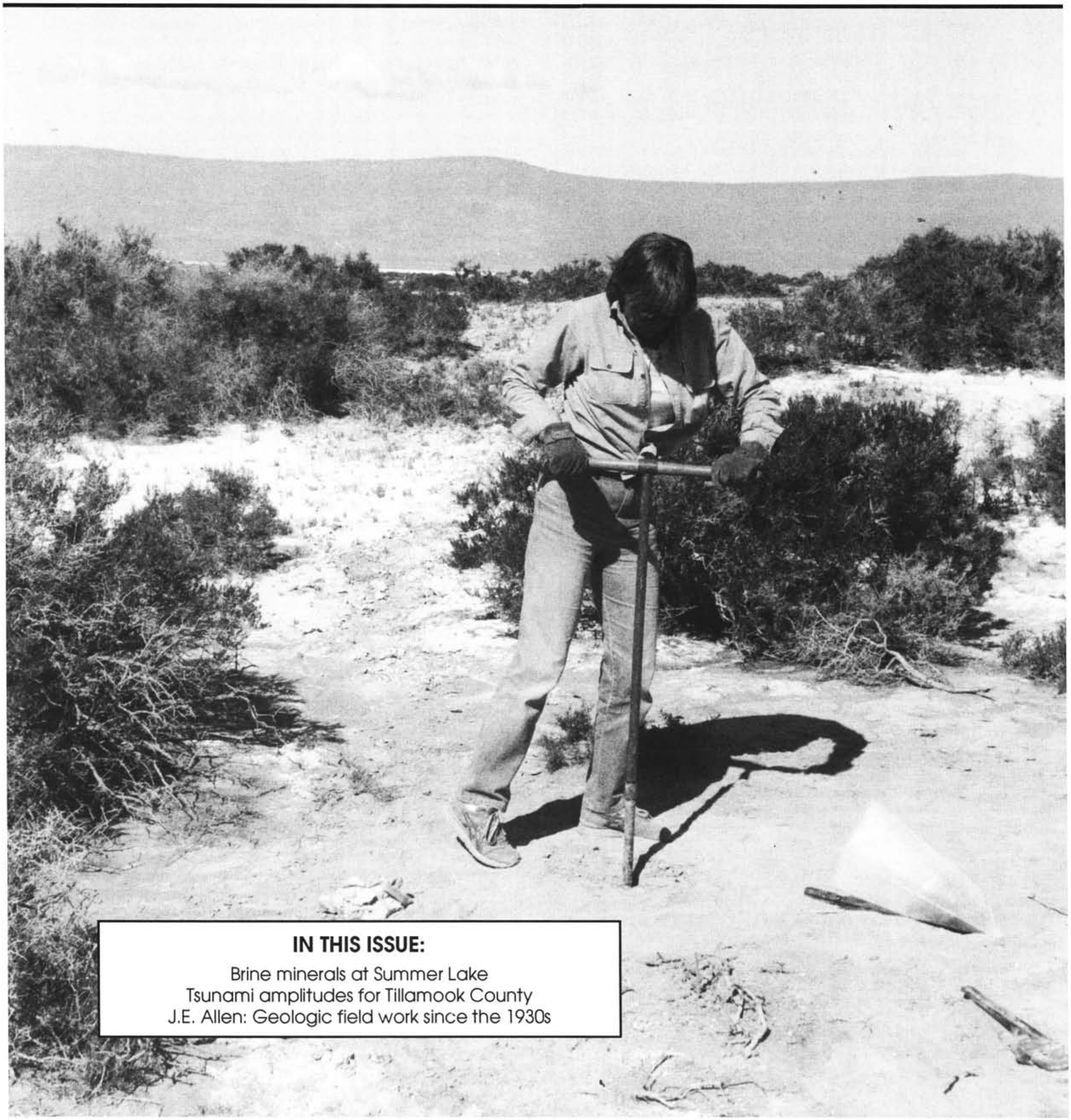
OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 56, NUMBER 3 **MAY 1994**



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OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 56, NUMBER 3 MAY 1994

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover photo

Augering for samples in a wind-deflated basin between sand dunes east of Summer Lake in Lake County. Resource studies of the Diablo Mountain Wilderness Study Area located here are the background for the discussion of brine minerals in article beginning on next page.

DOGAMI PUBLICATIONS

Released March 23, 1994:

Geology and mineral resources map of the Cleveland Ridge quadrangle, Jackson County, Oregon, by Thomas J. Wiley. Released as map GMS–73. Price $5.

The Cleveland Ridge 7½-minute quadrangle extends north from Boswell Mountain to the county border and includes Round Top near its western edge and a portion of West Fork Trail Creek in its northeast corner. The west half of the quadrangle includes outcrops of very old metamorphic rock. The area has been mined and prospected for mercury, copper, zinc, uranium, chromite, coal, and clay; and various kinds of stone have been mined for road construction.

Geology and mineral resources map of the McLeod quadrangle, Jackson County, Oregon, by Frank R. Hladky. Released as map GMS–80. Price $5.

The McLeod 7½-minute quadrangle includes Lost Creek Lake, Elk Creek Dam, and portions of the Rogue River and Elk Creek. The area is dominated by volcanic rocks that built the Western Cascades in this region. Hard rock—especially for construction of Elk Creek Dam—and pumice have been produced, while mercury and beryllium have been sought but not produced in the quadrangle. Some rocks from areas north of the quadrangle where the geology is similar have been found to contain significant anomalies of gold, silver, mercury, lead, and zinc.

Both maps are two-color maps at the scale of 1:24,000 (1 inch equivalent to 2,000 feet) and are accompanied by a separate sheet with tables of geochemical data and a text that explains rock units and discusses structure, geologic history, and ground-water and mineral resources.

Released March 28, 1994:

Beach-shoreline database, Pacific Northwest region, U.S.A., by Curt D. Peterson and a team of scientists from Portland State University, Oregon State University, and Western Washington University. Released as Open-File Report O–94–2. Price $12.

This report presents the first regional database of shoreline characteristics in Washington, Oregon, and California. It consists of one computer diskette and a 29-page text explaining the data sources, field methods, database access, and database components.

The ocean shoreline studied extends for about 1,000 km (621 mi) from Cape Flattery in Washington to Cape Mendocino in California. The database was developed from aerial photogrammetry data collected at about 2,000 reference points spaced at regular intervals and from profile data of representative littoral cells of the coastal zone.

The data in this report can be used to map and analyze the regional distributions of different types of shorelines, including rocky headlands, sandy beaches, tidal inlets, dune fields, and coastal terraces. Specific shoreline variables and beach parameters can be used to help predict regional shoreline susceptibility to (1) chronic and catastrophic hazards, (2) impacts from shoreline protection structures, (3) shoreline instability from sand mining or dredge spoil disposal, and (4) contamination from pollutants. Finally, the database can be integrated with other databases of, for example, wildlife habitat, recreational-economic interests, and jurisdictional boundaries for a wide variety of coastal inventory and planning uses.

The database is divided into three data files containing (1) beach physiography, (2) beach survey, and (3) beach deposit data. The files are in Excel version 4.0 spreadsheet format for either the Apple or DOS operating systems. The data can be used in compatible spreadsheet programs or loaded into relational database programs or geographic information systems (GIS). **Orders for this report must specify Apple or DOS format for the diskette.**

Earthquake database for Oregon, 1833 through October 25, 1993, by A.G. Johnson, D.H. Scofield, and I.P. Madin. Released as Open-File Report O–94–4. Price $10. *(Continued on page 64)*

Brine mineral occurrence in the Diablo Mountain Wilderness Study Area, Oregon, and its possible significance to Pacific Rim trade

by Thomas J. Peters[1]*, Michael F. Diggles*[2]*, and Dennis S. Kostick*[3]

ABSTRACT

The western or "Additional," part of the Diablo Mountain Wilderness Study Area, which borders the east shore of saline Summer Lake, has potential for undiscovered resources of soda ash, boron compounds, and sodium sulfate. Possible byproducts include potash, salts, bromine, lithium, magnesium compounds, and tungsten. Limestone from the study area could be used in the recovery process of brine components or in agricultural applications. Local power production from geothermal resources may be economically feasible.

Geologically, the study area lies on the northwest edge of the Basin and Range physiographic province, a region of fault-block-formed mountains and basins characterized by interior drainage. Consolidated rocks are mostly Tertiary basalt and tuffaceous sedimentary rocks. Low-lying areas are covered by Quaternary alluvial-fan, sand-dune, playa, lacustrine, and landslide deposits. The principal structural features are normal faults that have large vertical offsets; these faults are typically concentrated at the margins of large horst and graben structures.

Soda ash, soda ash products, and boric acid are widely used in the fluxing of metals and have important applications and markets in the aluminum industry in the Pacific Northwest and the developing Pacific Rim. Evaporite commodities are essential to many "backbone" industries and to many new applications and advanced materials. Markets for brine mineral products appear to be undergoing steady and strong growth, especially in the Pacific Northwest and in Pacific Rim countries. Soda ash produced near the study area would be 55 percent closer by rail to marine export at Portland, Oregon, than trona deposits of the Green River (Wyoming) district.

Soda ash and a daughter product, caustic soda, and sodium borohydride will receive increased application in the bleaching of paper pulp for environmental reasons. Caustic soda, used in many industrial processes, is more environmentally friendly when derived from soda ash than when produced from sodium chloride salt, because of the absence of a chlorine byproduct. Sodium sulfate is increasingly substituted for less environmentally friendly phosphates in laundry detergents. Producing soda ash from brines, a type of "in situ" mining, can be done with minimal environmental degradation, and mining natural soda ash is environmentally as well as economically preferable to synthetic soda ash production.

INTRODUCTION

A brine mineral occurrence of possible economic significance was documented along the east shore of Summer Lake, Lake County, Oregon, in the 34,310-acre western or "Additional" portion of the Diablo Mountain Wilderness Study Area as the result of a mineral survey requested by the U.S. Bureau of Land Management. The various phases and conclusions of this survey, as described by Diggles and others (1990b), resulted from a cooperative effort by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey (USGS) and form the basis of the present paper.

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[3] *U.S. Bureau of Mines, 810 7th Street NW, Washington, D.C. 20241.*

The Diablo Mountain Wilderness Study Area is situated 45 mi north of Lakeview and 5 mi north of Paisley in Lake County, Oregon (Figures 1 and 2). Elevations in the area range from 4,300 ft near the shore of Summer Lake to 6,147 ft at the summit of Diablo Mountain. Access to the region is via Oregon State Route 31, connecting with U.S. Highways 395 north of Lakeview and 97 south of Bend. Access to the study area is provided by dirt roads leading off State Highway 31. Access within the study area is by four-wheel-drive vehicle on jeep trails, by mountain bicycle, and by foot.

The climate is semiarid, and the average annual precipitation is about 12 in. The sparse rainfall in the area results in only intermittent stream flow. The region contains several lakes, of which Summer Lake is one, that occupy closed basins. Vegetation consists of low-growing desert shrubs, mostly sagebrush, greasewood, creosote bush, burroweed, and boxthorn (Figure 3).

GEOLOGY

The Diablo Mountain Wilderness Study Area is underlain by sedimentary and volcanic rocks of Tertiary and Quaternary age (Diggles and others, 1990a) (Figure 4). They are generally flat lying

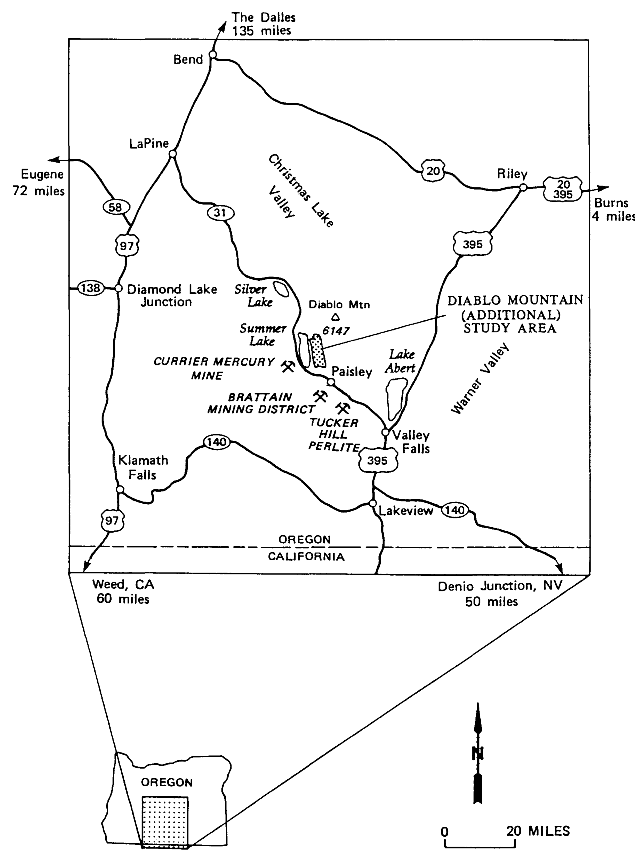

Figure 1. Location of the Diablo Mountain (Additional) study area, Lake County, Oregon (from Peters and Willett, 1989).

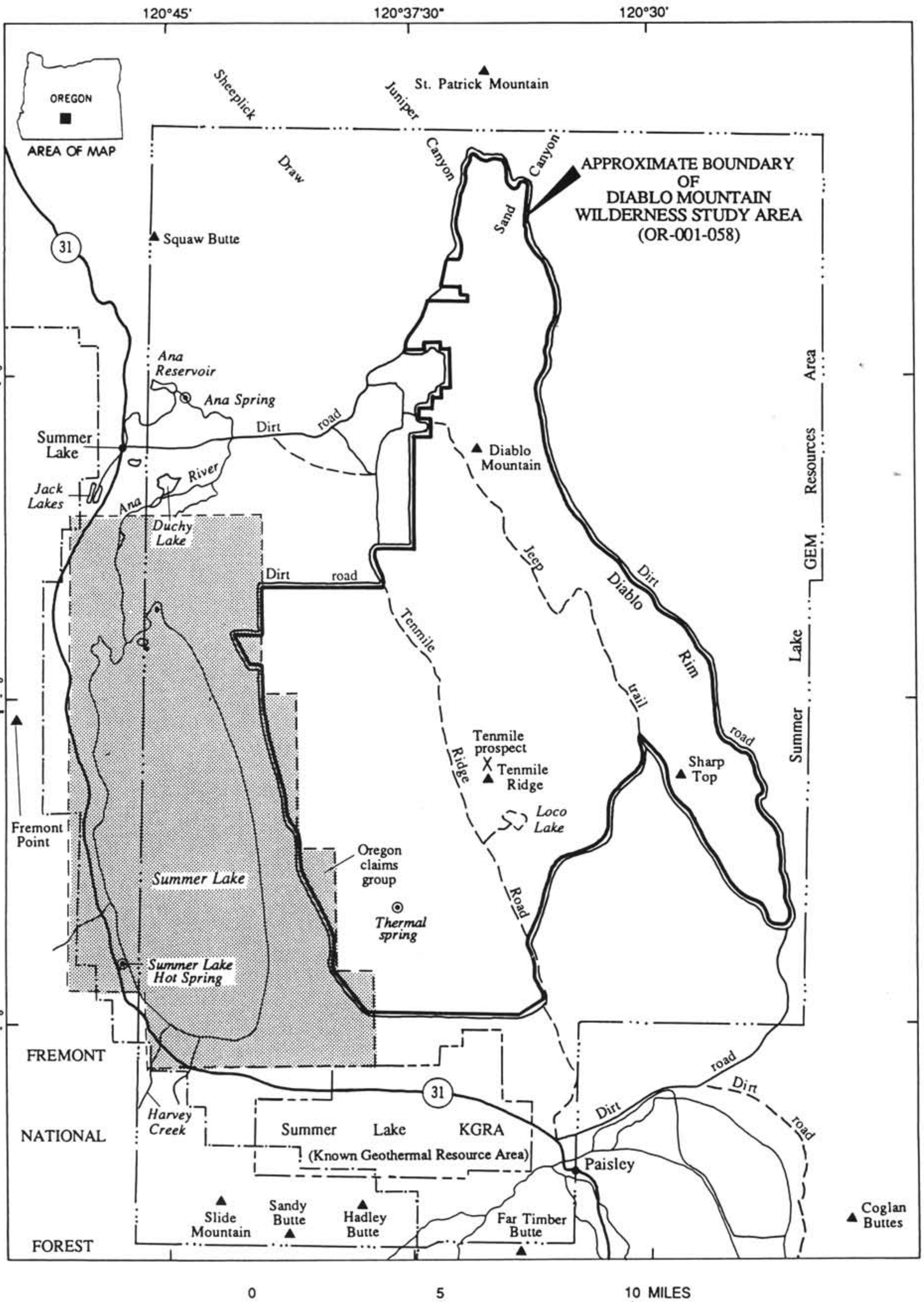

Figure 2. Diablo Mountain Wilderness Study Area, Lake County, Oregon. "Additional" study area discussed in this paper is located mostly west of Tenmile Ridge Road. Shaded area marks Oregon Prospect (Oregon claims group). From Diggles and others, 1990b.

Figure 3. Playa area east of Summer Lake, capped by intermittent sand dunes that are anchored by vegetation. Location is auger site R (see Figure 5); view is to the northeast.

but are broken by normal faults. Tertiary rocks in the study area consist of basalt flows, basaltic pyroclastic rocks, tuffaceous sedimentary rocks, rhyolitic tuff, and dolomitic limestone.

The Summer Lake basin was occupied by pluvial Lake Chewaucan. Sediments in the basin include tephra from several large volcanic eruptions. Landslides from Winter Rim, west of Summer Lake, between 19,000 and 12,000 years ago locally compressed and deformed the sediments (Simpson, 1989).

Structurally, the study area lies on the northwest edge of the Basin and Range physiographic province. Summer Lake occupies a closed basin bounded by ridges that have fault-scarp fronts (Phillips and Van Denburgh, 1971). The structural geology of the study area is dominated by high-angle north-northwest-trending normal faults that have cut the range into blocks. J.J. Rytuba (personal communication, 1987) suggested that the Summer Lake area, including the area to the east, now covered with dunes, may be a large caldera.

The Diablo Rim is the most extensive scarp resulting from the faulting (Figure 4). The study area is bounded on the northeast by the north-northwest-trending Brothers fault zone that has been interpreted as a transcurrent structure that bounds the northwest edge of the Basin and Range physiographic province (Lawrence, 1976). The area on the west side of Summer Lake and south of the study area is part of the poorly defined Modoc Plateau physiographic province that separates the Basin and Range and the Cascade Range physiographic provinces (Macdonald, 1966). Vertical offset in the study area is apparent at the margins of large fault-bounded horst and graben structures typical of the Basin and Range.

THE OREGON PROSPECT

Exploration history

Lake County mining records indicate that a large block of 326 placer claims was located in 1901 by an eight-person association and was relocated by the same claimants in 1906. Historically known as the Oregon claims group (Figures 2 and 5) and discussed here as the "Oregon prospect," the claims area extended from 2 mi north to 1 mi south of Summer Lake and as much as 2 mi east and 1 mi west; it included the entire lake and the surrounding playa. The discovery, according to the records, was for "the valuable metals, sodium and potassium and their compounds of bicarbonate of soda, carbonate of soda and potassium sulfate, in paying quantities held in solution and in deposit." The claimants were Charles M. Sain; John T. Reid; Schuyler Duryee; W.F. Brock; and William, Charles, Canby, and Elwood Balderston. The eastern claim block boundary extended north-south along the western part of the study area.

With the outbreak of World War I, foreign potash supplies were cut off, and the price for potash increased from $0.80 to $8.00 per unit (20 lb). In 1916, the first successful plants to produce potash and other evaporite minerals from brine came on line at Searles Lake, California (Teeple, 1929). On December 16, 1914, the State of Oregon leased the mineral rights to soda salts in Abert and Summer Lakes on a royalty basis (Hartley, 1915). Ambitious development plans included a 270-mi pipeline north to the Columbia River and a large hydroelectric plant, an investment of about $7 million (Phalen, 1916, p. 107-108). Outside but adjacent to the south boundary of the study area are remnants of a water retention levee and an evaporation pond (Figure 6). These were apparently developed in 1918; John Withers, a local rancher, recalls that much money and effort was spent that year by a crew of men led by one Jason Moore. After the armistice, the potash price dropped and by mid-1919 was at $1.75 to $2.00 per 20-lb unit. Perhaps this was the main reason for not continuing the work at Summer Lake.

Resource

The Oregon claims group, inactive since 1918, covered all of Summer Lake, including the west margin of the Diablo Mountain Wilderness Study Area (Figure 2). The prospect was primarily for brines; no conventionally minable beds of evaporite minerals are known. Summer Lake waters are not sufficiently concentrated to

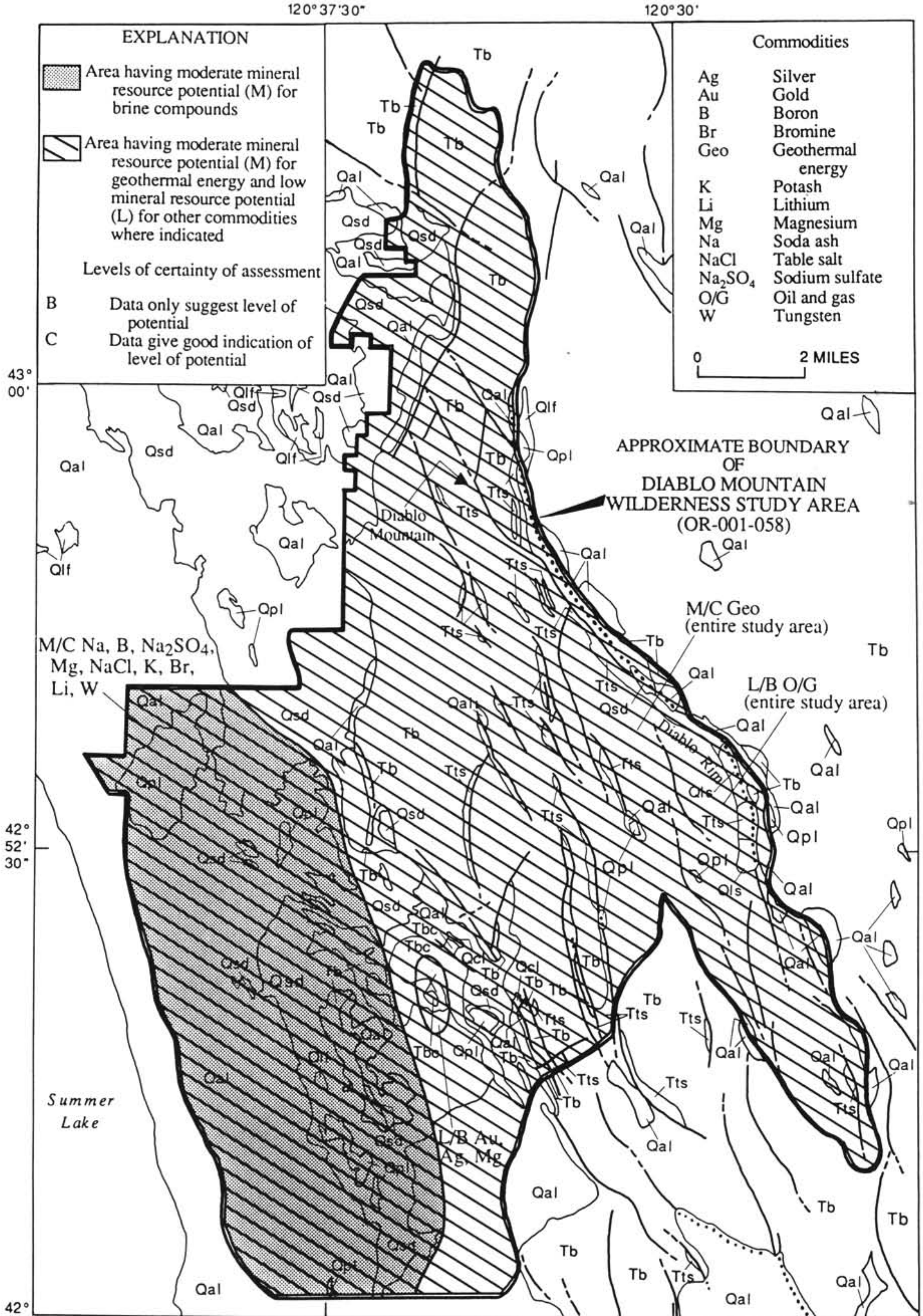

Figure 4. Generalized geology and mineral potential of the Diablo Mountain Wilderness Study Area, Lake County, Oregon, from Diggles and others (1990b). Geologic units: Qal = alluvium, Qsd = sand dunes, Qpl = playa deposits, Qlf = lacustrine and fluvial deposits, Qls = landslide deposits, Qcl = claystone, Tbc = basaltic cinders, Tb = basalt, Tts = tuffaceous sedimentary rocks. Faults are marked by solid lines that are changed to dashed where approximately located and to dotted where concealed.

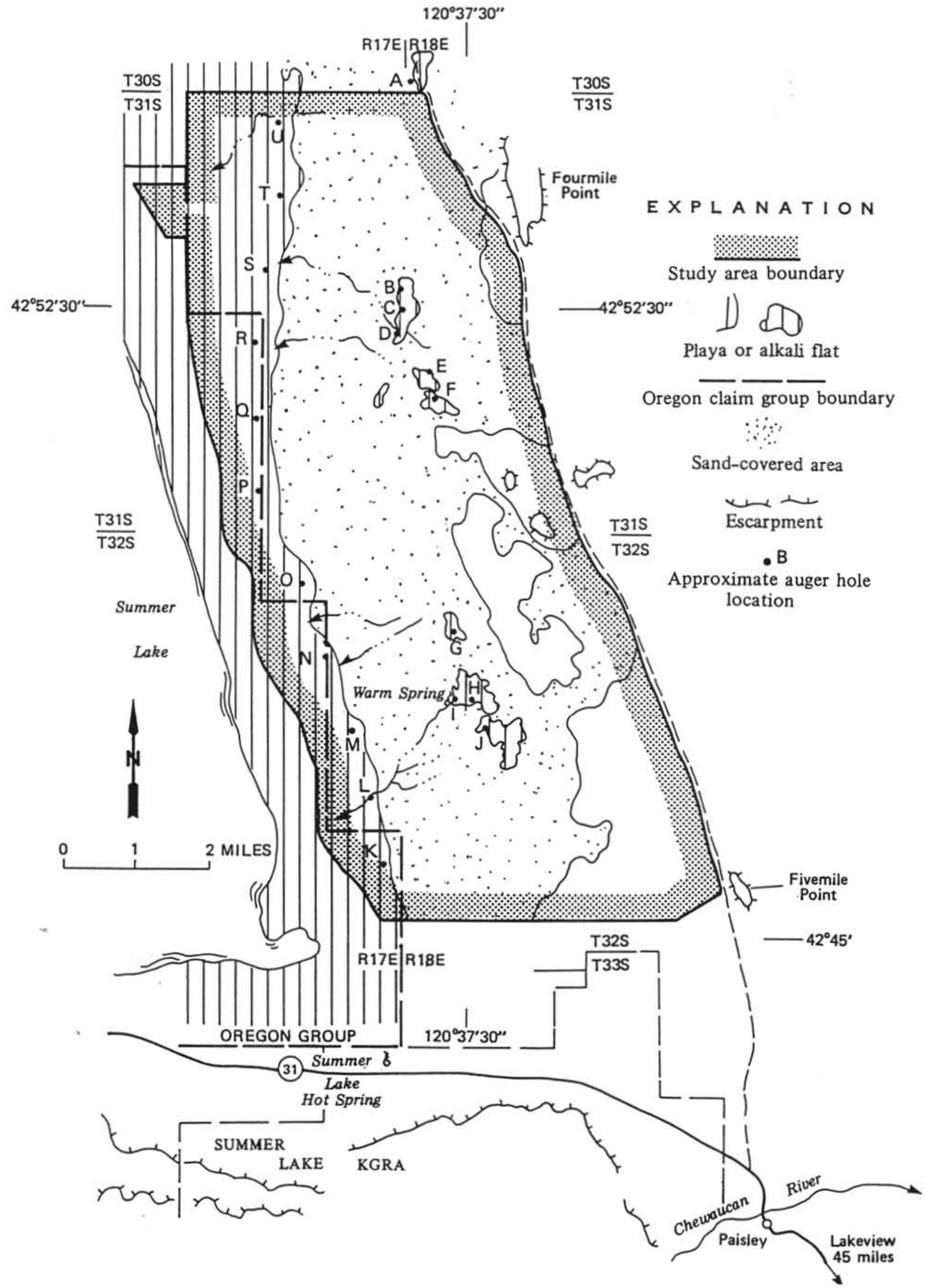

Figure 5. Auger hole localities (A–U) in the Diablo Mountain (Additional) study area. Dashed line along the east boundary of the study area is the Tenmile Ridge Road. From Peters and Willett, 1989.

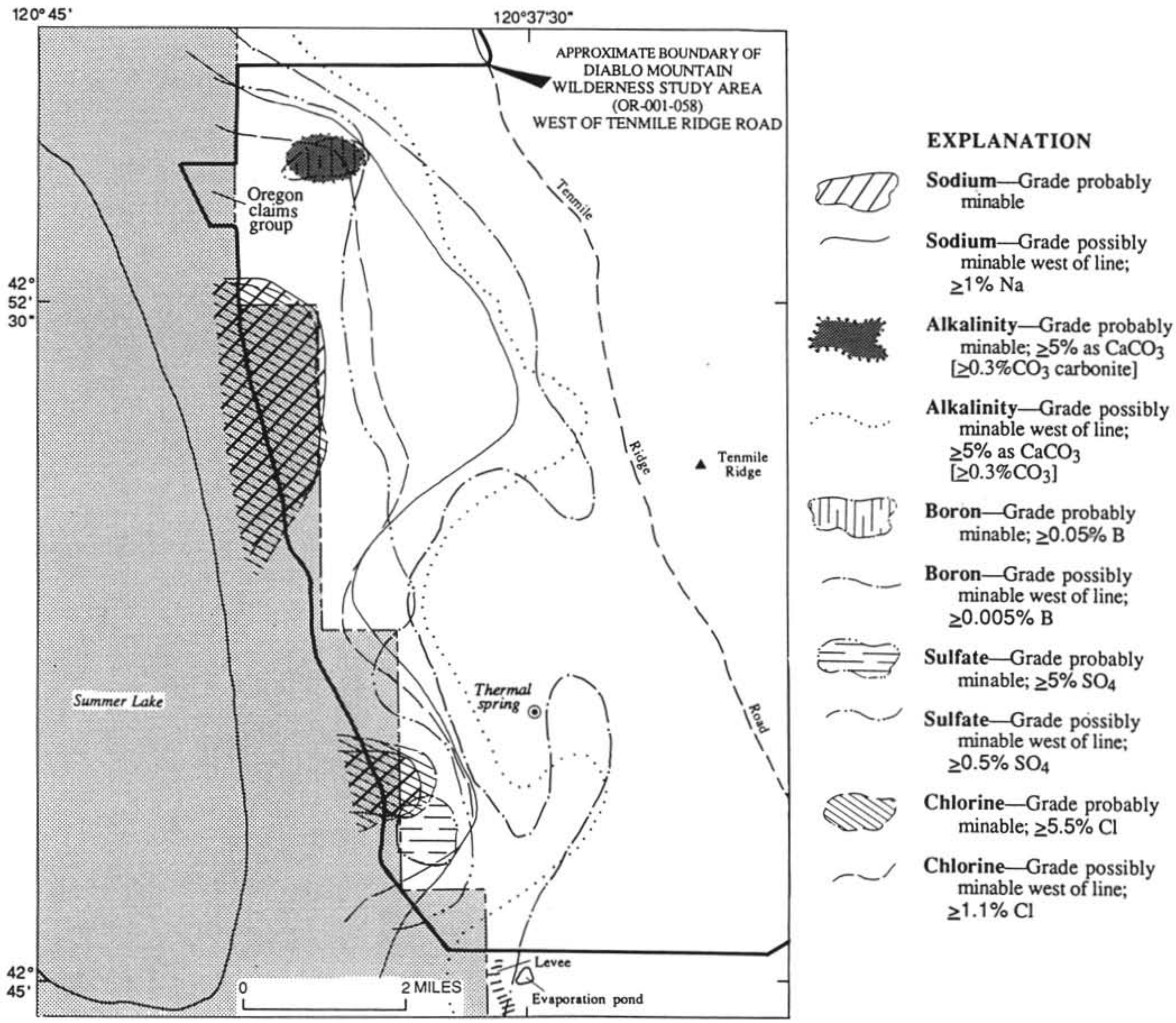

Figure 6. Concentrations of chemical components of brine commodities in ground water in the Diablo Mountain (Additional) Study Area (from Diggles and others, 1990b).

be a source of resource-bearing brine. In 1969, the lake, with a maximum water depth of about 3 ft, contained a calculated total of only 1 million tons of mineral salts; however, the top 5 ft of lake-bottom and marginal sediments contained 15 to 20 million tons of evaporite minerals. The greatest quantities of evaporite minerals are under the eastern playa rather than under the lake (Van Denburgh, 1975). Seasonal variation of fresh water and evaporation renders the solute concentration too inconsistent for the lake waters to constitute a brine source for year-round processing. Interstitial brines sampled from auger holes (Peters and Willett, 1989, Tables A-1 and A-2) are much higher in solutes than the lake-water samples reported by Van Denburgh (1975, Table 4).

Within the study area, brine-hosting lake and playa sediments define a mineral area extending more than 2 mi east of the claims group. Much of this area is covered by a veneer of windblown sand as much as several tens of feet thick. Several flat-floored blowout basins, displaying the white surface efflorescence that is characteristic of areas underlain by evaporative brine, have formed windows through the sand.

Brine commodity evaluation

Sampling of the mineral area by hand auger (Figure 7) yielded data on the mineral and brine composition of the top few feet of sediments and allowed comparison with chemical data from analogous mineral systems that are better understood. An appropriate place for comparison is Searles Lake, California, about 500 mi to the southeast, where evaporite commodities have been extracted from brines and evaporite deposits for more than 50 years (Smith, 1979).

Brine samples were analyzed for cation (+) and anion (–) components of evaporite commodities that include soda ash, boron compounds, sodium sulfate, salts, potash, and lithium. Samples were also analyzed for arsenic and antimony, which are not only possible toxic contaminants but are also indicators of nearby epithermal mineralization or mineralizing processes. The auger-hole sediments and alkali crusts were analyzed for major-element oxides and 36 trace elements. Possible products, based on component concentrations (Figure 6) and commodity economics, include soda ash (sodium carbonates), boron compounds, and sodium sulfate. Possible

Figure 7. Hand auger for collecting water and sediment samples on playa, east of Summer Lake. (See also cover photo.) Location is auger site L; view is to the northwest.

byproducts include potash, salts, bromine, lithium, magnesium compounds, and tungsten; their production may be feasible in conjunction with other commodities. Processing of many of the products could be facilitated by treating them with dolomitic limestone, which is also present in the study area.

Our brine analyses were compared to published analyses of brines from Searles Lake, California (Smith, 1979, Tables 5, 16, and 22) (Figure 8). Ranges of concentration of possible significance now or in the foreseeable future were chosen by using the Searles Lake operation as a guide. Our cutoffs are lower than those for the Searles Lake brine concentrations because (1) low concentrations in surface samples do not preclude higher concentrations at depth, (2) advances in extractive technology allow utilization of lower grade brines (Smith, 1979), (3) the advantage of large-scale application of such technology is inherent in designing new facilities, and (4) possible markets may be closer.

Two categories of brine commodity occurrence, based on their chemical component concentrations, were chosen: a grade probably minable, and a grade possibly minable (Figure 6). Occurrences of probable economic concentrations are defined as approximately equal to or greater than 50 percent of the grade of Searles Lake brines for all products except boron, which is of higher unit value. The grades of possibly minable brines in the study area are equal to or greater than 10 percent of the grade of Searles Lake brines. Boron could possibly be mined economically from lower grade brines than those at Searles Lake by the use of advanced technology in new plant design (Gail Moulton, personal communication, 1989). Grades of brine components at least as good as the possibly minable grade were observed at 12 auger sites and 4 seeps (Table 1).

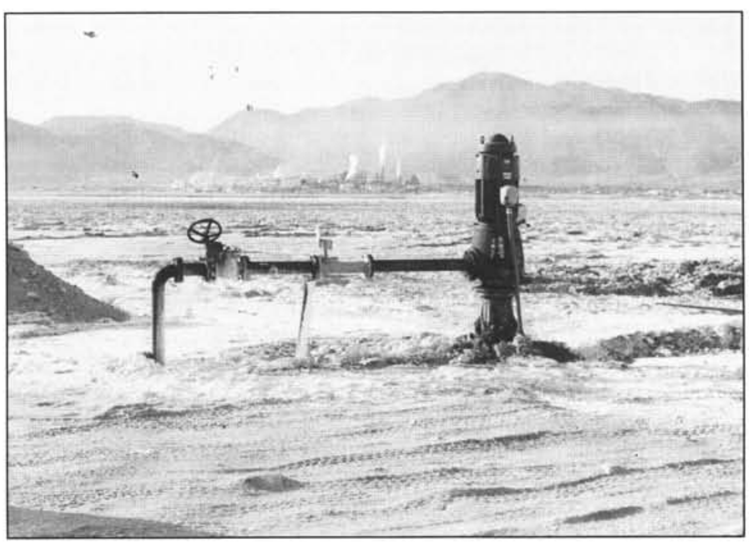

Figure 8. Brine well on Searles Lake, California. View toward northwest shows Trona plant of North American Chemical in the distance.

In Figure 6, isocon maps (contour maps of chemical concentrations) of the sodium, alkalinity (as $CaCO_3$), boron, sulfate, and chlorine concentrations (Peters and Willett, 1989, Figures 3–6) were generalized and combined. Areas interpreted to have probably minable grades were denoted by patterns. Grades of brine components having possible economic significance extended east of the Oregon claims group but were highest in the claim block vicinity.

The Tenmile and other dolomitic limestone prospects

In addition to the potential resources in the Oregon prospect, a dolomitic limestone of Pliocene(?) age is locally interbedded with basalt flows at the Tenmile and other dolomitic limestone prospects. This limestone appears to have formed as an apron along the east, northeast, and north flanks of Tenmile Ridge and may extend for 2 mi to the northwest. It crops out discontinuously through a veneer of sand dunes and desert pavement. The rock is suitable for brine mineral processing and agricultural applications. Usually, the thickness could not be determined, but Harold Dyke of Adel, Oregon, (personal communication, 1988) reports the rock is as thick as 30 ft northeast of Tenmile Ridge.

In March 1974, a group of claims including the Tenmile prospect and six others was located for limestone on the northeast side of Tenmile Ridge. Claimants included Harold J., and Marie Dyke of Adel, Oregon; Frances M. Foster; Con O'Keefe; Laura Shine; Jerry and Julia Singleton; and Morgan Verling. John Cremin (Lakeview, Oregon) examined the prospect in 1980, brought it to the attention of the authors, and reported that exposures of the limestone extend into the study area.

Geothermal energy

Summer Lake Hot Spring (Figure 5) produces 116°F water at a rate of 21 gallons per minute (Peterson and McIntyre, 1970) and is developed as a resort. The presence of the thermal spring, in part, resulted in the designation of the Summer Lake Known Geothermal Resource Area (KGRA) 2 mi south of the study area. The KGRA includes three additional geothermally significant wells (Oregon Department of Geology and Mineral Industries, 1982, wells Lk-7, -8, -9, -10). Of special interest are the Collahan wells Lk-9 and Lk-10, which have water temperatures of 212°F and 231°F, respectively, but do not produce dry steam, the most efficient medium for electric power generation. However, water temperature at the Summer Lake KGRA is much higher than the 100°F minimum needed for electric power production by the binary systems process (Rinehart, 1980).

MINERAL ECONOMICS

Soda ash

Soda ash (sodium carbonate, Na_2CO_3) has been recovered from brines at Searles Lake by two methods: an older evaporation process, and a direct carbonation process. The evaporation process involves heating the brines, which causes the double salt burkeite ($Na_2CO_3 \cdot 2Na_2SO_4$) and table salt (NaCl) to precipitate. The remaining liquor is rapidly cooled, and potassium chloride is precipitated and filtered out. The remaining brine is supersaturated with sodium borate, which

Table 1. *Occurrence of brine commodity components in the Diablo Mountain (Additional) study area, Lake County, Oregon. * = Concentration possibly minable[1]; ** = Concentration probably minable[2]; n.a. = not applicable; — = not available; ppm = parts per million*

Auger hole (A-U)	Brine sample number	Hole depth (ft)	Weight percent water[3]	Alkalinity as $CaCO_3$ percent	Concentration[4] B+ (percent)	Cl– (percent)	K+ (percent)	Li+ (ppm)	Na+ (percent)	SO_4^{--} (percent)
D	18 b	8	21.68	*4.48	*0.0250	0.68	0.100	< 0.1	*3.40	0.10
F	31 b	8.4	34.16	*0.91	*0.0075	*1.30	0.022	< 0.1	*1.30	0.27
H	47 b	6	22.46	*0.74	*0.0063	0.50	0.022	< 0.1	0.97	0.21
J	65 b	5.6	28.44	*1.52	*0.0124	0.97	0.038	< 0.1	*1.30	*0.41
K	69 b	4	29.74	0.44	*0.0080	0.27	0.053	2.0	0.57	0.29
Seep	70 b	n.a.	—	*0.66	*0.0067	0.35	0.025	< 0.1	0.69	0.39
Seep	71 b	n.a.	—	*0.72	*0.0059	0.33	0.017	< 0.1	0.55	0.29
L	75 b	4	31.61	*2.63	*0.0230	*3.00	0.090	< 0.1	*3.30	**6.90
M	78 b	4	39.97	*2.58	*0.0230	**5.70	0.110	0.3	**5.20	0.62
N	81 b	4	34.71	*1.77	*0.0140	*1.50	0.045	< 0.1	*1.90	0.35
Seep	82 b	n.a.	—	*0.75	*0.0059	0.32	0.017	< 0.1	0.59	0.16
O	85 b	4	40.44	—	*0.0065	—	0.053	0.9	0.68	n.a.
P	88 b	4	36.59	*2.47	*0.0250	—	0.045	< 0.1	*4.90	*0.58
R	94 b	5.9	42.84	*2.92	*0.0390	**5.60	0.130	< 0.1	**5.30	*0.60
Seep	97 b	n.a.	—	*1.94	*0.0160	*1.30	0.032	< 0.1	*2.00	*0.40
T	100 b	4	28.30	**5.43	**0.0500	*2.70	0.110	< 0.1	*4.70	*1.20

[1] Possibly minable concentrations are within one order of magnitude of those of Searles Lake brines (Smith, 1979, tables 9, 16, and 22), except boron is within two orders of magnitude.
[2] Probably minable concentrations are equal to or greater than one-half of those of Searles Lake brines (Smith, 1979), except boron is within one order of magnitude.
[3] Weighted average weight percent water of wet sediment sample from auger hole.
[4] Percent multiplied by 10,000 equals mg/L; ppm approximates mg/L.

is precipitated after the addition of "seed" crystals (Gail Moulton, North American Chemical Corporation, personal communication, 1989). In the direct carbonation process, brine is mixed with carbon dioxide (CO_2) gas. At Searles Lake, carbon dioxide is produced from power-plant flue gases (Parkinson, 1977); but traditionally, carbon dioxide has been produced from lime kilns.

The soda lakes of south-central Oregon are similar in appearance and composition to other surface lakes with evaporite crusts and subsurface brines found worldwide. These types of soda deposits provided the crude sodium carbonate used about 3,500 B.C. by the Egyptians to make glass ornaments and containers and in medical and food-additive applications. Although people in Europe and America used the ashes of wood to obtain alkali by burning plants found in salt-bearing soils or seaweed and leaching the residue to produce "soda ash" (a term that is still in use today), they soon discovered natural soda in many surface evaporite deposits.

The first commercial soda ash operation in the United States began in the 1860s at Little Soda Lake at Ragtown, Nevada, near the present town of Fallon. Workers excavated the evaporated crude sodium carbonate found along the margin of the lake. Imports of soda ash from Europe supplemented the soda alkali needed for glass and detergent manufacturing. Although the Leblanc process that originated in France produced an impure soda ash, it was not until the 1860s that a technique to make synthetic soda ash was developed. Because the continued use of burning seaweed and plants became economically impractical, and supplies were becoming scarcer, synthetic soda ash production increased throughout the world. In addition, because trona (the primary ore of soda ash) and some of the other carbonate-bearing minerals are water soluble, there are not very many economic surface deposits found in the world despite the numerous occurrences of sodium carbonate commonly associated with many evaporite resources.

The birth of the modern natural soda ash industry began in California in 1887 at Owens Lake and was further developed in 1931 at Searles Lake and in 1948 at Green River in Wyoming. Because deposits were in the west, the majority of markets tended to be within that region. The remainder of the nation used synthetic soda ash, which was first produced in the United States at Syracuse, New York. At one time, ten synthetic plants were operating in the northeast, east, upper midwest, and on the Gulf coast. The rivalry between natural and synthetic soda ash continued for many years. Because world production capacity was adequate to meet demand, the United States exported very little soda ash prior to 1970.

During 1992, soda ash was produced by five companies in Wyoming and one company in California; total estimated value was $837 million. Industrial use of soda ash was in the following proportions: glass, 48 percent; chemicals, 24 percent; soap and detergents, 13 percent; distributors, 6 percent; flue gas desulfurization, 3 percent; pulp and paper, 2 percent; water treatment, 2 percent; and other, 2 percent (Kostick, 1993). In 1992, the United States exported 3.3 million tons of soda ash; a total of 43 percent went to all Asian countries, the largest export market.

Boron compounds

Generalized boron concentrations of the brines in the study area are shown on Figure 5. Processing of these brines probably would be similar to extraction methods at Searles Lake, California, where brines containing boron are mixed with a liquid extractant that removes boron from the brine. Boron is then purged from the extractant with sulfuric acid, producing boric acid [$B(OH)_3$]. Sodium and potassium sulfate remain in the liquor and can be recovered.

Boron, though unfamiliar to most people, has many uses. Borates have been used as a flux in metal smithing since their introduction into Italy from Mongolia in the 13th century, and they were used to add strength to glass made by medieval European artisans. Elemental boron was isolated in 1808. The boron mineral tincal ($Na_2B_4O_7 \cdot 10\,H_2O$) was discovered at Teel's Marsh, Nevada, in 1872 and ulexite ($NaCaB_5O_9 \cdot 8\,H_2O$) was discovered in Death Valley, California, in 1881. By 1927, underground mining of a massive tincal and kernite ($Na_2B_4O_7 \cdot 4\,H_2O$) deposit had begun at Boron, California. Mining was converted to open-pit methods in 1957. U.S. Borax annually produces about one-half of the world's boron from these deposits. North American Chemical Company produces boron compounds as coproducts of solution mining of soda ash at Searles Lake (Trona, California; Figure 8). For further detail about the boron industry, see Lyday (1985).

The United States is currently the largest producer of boron compounds (Lyday, 1993). Of the total production, 62 percent is used in glass making, 9 percent in soaps and detergents, 5 percent in fire retardants, and 24 percent in other uses (Lyday, 1993). Borosilicate glass withstands severe temperature changes without cracking. Borate compounds are used as metal solvents and fluxes in the metals industry, as both herbicides and plant nutrients in agriculture, in fire retardants, and in heat-resistant ceramic products such as the tiles that protect the space shuttle during reentry. Elemental boron fibers are used with tungsten-steel alloys for high strength in helicopter rotors; boron nitrite approaches the hardness of diamond and is more heat resistant. Sodium borohydride is used in the bleaching of ground wood (Rex McKee, personal communication, 1989), and there are many additional applications for boron compounds.

Sodium sulfate

Sodium sulfate occurs in two economically important mineral forms: mirabilite or Glauber's salt ($Na_2SO_4 \cdot 10\,H_2O$) and thenardite (anhydrous Na_2SO_4). Almost all commercial deposits are lacustrine evaporites (Weisman and Tandy, 1975). Sodium sulfate can be extracted from brine as a coproduct of soda ash and boron compounds. Only about 48 percent of comes from natural sources; most is manufactured as a byproduct of chemical and rayon factories. End uses are in soap and detergents, 44 percent; pulp and paper, 24 percent; textiles, 16 percent; glass, 5 percent; and miscellaneous uses, 11 percent (Kostick, 1993). Increasingly, sodium sulfate is used as a substitute for phosphates in laundry detergents. Phosphates endanger the oxygen content of streams and lakes because they encourage excessive growth of algae.

In the study area, sodium sulfate as a mineral commodity is closer to pulp and paper markets in the northwestern states than are current sources of sodium sulfate.

Byproduct brine commodities

Production of six byproduct commodities from the study area may be feasible: table salt (NaCl), potash (K_2O; and muriate of potash, KCl), bromine, lithium, magnesium compounds, and tungsten. Byproduct salts are produced at Searles Lake, California. Two companies in Portland, Oregon, currently buy imported Mexican salts for the manufacture of caustic soda and chlorine compounds. It may be economical to recover magnesium compounds from the site of the Oregon claims group. A local source of dolomitic limestone to be used in processing the brines would make additional magnesium available for byproduct compounds. The additional investment needed to extract byproducts from a resource-producing brine, even at low concentration, may be somewhat small. Distribution of byproduct concentrations and uses are discussed in more detail by Peters and Willett (1989).

Dolomitic limestone

The dolomitic limestone occurrence along Tenmile Ridge may be useful for its possible application in brine commodity processing. Carbon dioxide produced from the calcination of limestone or dolomite is used to remove calcium from brines, thus allowing further separation of soda ash, boron compounds, and sodium sulfate. A calcination byproduct, calcium hydroxide can then be used to convert soluble magnesium salts into insoluble magnesium hydroxide, which in turn can be calcined to produce magnesia. Another proposed use of the limestone is as a soil conditioner; this may be feasible if there is enough limestone and if low-cost rail transportation is available in conjunction with development of other mineral commodities.

MARKETS AND TRENDS

Of the 10.4 million short tons of domestic soda ash produced in 1992, 3.3 million tons was exported to 51 countries throughout the world (Figure 9). The soda ash was used to manufacture glass bottles, window glass, soaps and detergents, and various inorganic chemicals.

The United States is the world's largest producer of soda ash, comprising about one-third of total world output. The majority of the world's production is synthetic soda ash, made with salt and limestone as feedstocks. Synthetic soda ash is more expensive to manufacture than natural soda ash. It also generates more pollution and is very labor intensive. Because of the higher cost of synthetic soda ash, exports of U.S. soda ash are expected to increase throughout the remainder of the decade.

The emergence of the United States as a soda ash exporter has its roots in two important events of the early 1970s. These were (1) the Arab oil embargo in October of 1973 that caused fuel prices to soar and (2) the ecology movement within the United States that prompted enactment of antipollution legislation. Producing a ton of synthetic soda ash takes about twice the amount of energy as producing a ton of natural soda ash. The synthetic process also generates byproduct sodium chloride and calcium chloride, both of which were usually discharged by plants as waste effluents and are considered detrimental to the environment. Of the ten synthetic soda ash plants that were constructed in the nation, seven were in operation when the energy and environmental problems emerged in 1973. By the end of 1979, only one remained in production: Ironically, it was the Syracuse plant, which was the first one built in the United States. This plant finally ceased operation in 1986, ending the era of synthetic U.S. soda ash production.

The energy and environmental issues that led to the demise of the U.S. synthetic soda ash industry began to surface in Europe and elsewhere in the world in the early to mid-1980s. The "green movement" in Europe identified some of the "synthetic" plants as contributors to Europe's air and water pollution, which forced less economic plants in Czechoslovakia, England, France, and Switzerland to close. A similar situation occurred in Asia and South America. Foreign manufacturers of glass and chemicals wanted to obtain less

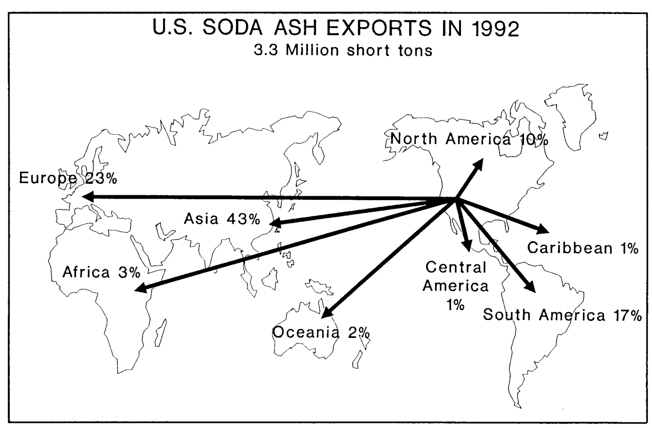

Figure 9. U.S. soda ash exports in 1992.

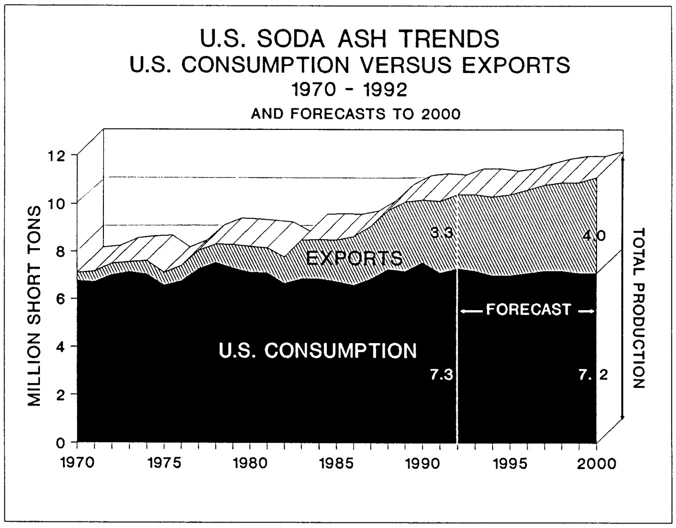

Figure 10. U.S. soda ash trends.

expensive soda ash, and the United States began to increase exports to these markets.

By 1982, five companies in Wyoming and one in California were exporting 14 percent of domestic output (Figure 10). The industry formed the American Natural Soda Ash Corporation (ANSAC) to promote export sales and was able to ship natural soda ash more efficiently. From 1970 through 1992, U.S. apparent consumption increased 6 percent, while exports rose a dramatic 869 percent.

The Pacific Northwest

Markets for brine-mineral products appear to be undergoing steady growth, especially in the Pacific Northwest (Figure 11) and in Pacific Rim countries. By volume, soda ash, also known as sodium carbonate, ranks 11th among the inorganic chemicals produced in the United States. It is obtained domestically by processing trona ore from the world's largest deposit in Green River, Wyoming, or from underground sodium carbonate-bearing brines found at Searles Lake, California. Other sodium carbonate deposits, such as those in Summer Lake and Lake Abert in Oregon, are potentially important.

Soda ash and a daughter product, caustic soda, and sodium borohydride have found increased use in the bleaching of wood pulp. At present, for most pulping an alkali process is used. Only a few older and specialty mills use an acid process. Most paper bleaching is still done by the Kraft process, which produces chlorinated wood wastes that can evolve into dioxin and chloroform waste that is disposed of through smoke stacks. The next several years will see a complete transfer to alkali bleaching, which will use large tonnages of caustic soda from a soda ash source through a modified Solvay process (Jerry Gess, 1993, personal communication). The new process will be more energy efficient, and many chemicals will be recovered from waste products.

Alkali bleaching is ecologically preferable to the current acid process that uses chlorine compounds and produces a carcinogenic dioxin waste product. Soda ash, soda ash products, and boric acid are widely used in the fluxing of metals, also in the aluminum industry in the Pacific Northwest and in developing Pacific Rim countries. Evaporite commodities are essential to the backbone industries of many civilizations and to many new applications and advanced materials.

For products from the Oregon prospect, bulk commodity transport by railroad is available from Lakeview, Oregon, 45 highway miles to the southeast. There are no weight restrictions on the 55-mi-long Great Western Railroad shortline from Lakeview to Alturas, California; rail distance from Alturas to Portland, Oregon, is 415 mi. Railroad infrastructure could be extended from Lakeview to a new mine site for about $300,000 per mile (land not included) (Edward Emmel, Oregon Department of Transportation, Salem, personal communication, 1994), possibly in conjunction with other bulk product development such as perlite from the Tucker Hill deposit 14 mi southeast of the study area (Wilson and Emmons, 1985). In this scenario, brine minerals could be shipped by rail directly to Portland or Coos Bay, in either case a distance of about 520 mi. This distance is only 55 percent of the 912 mi of rail distance between Portland and the premier trona producing area, the Green River district in southwest Wyoming.

Although soda ash currently is produced in the United States by five companies in Wyoming and by one in California (with another in the pre-development stage at Owens Lake), the Oregon soda lakes could be important to soda-ash-consuming industries in the Pacific Northwest. The lakes are also within the range of some of the glass container plants of northern California, as well as Portland port facilities that handled about 60 percent of the U.S. soda ash export business and the port of Coos Bay, which can provide suitable facilities for new customers.

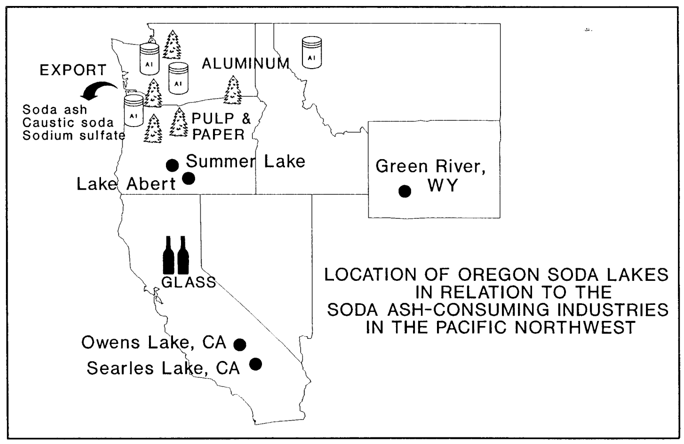

Figure 11. Location of Oregon soda lakes in relation to the soda ash-consuming industries in the Pacific Northwest.

The Pacific Rim

The Pacific Rim represents an important region for U.S. soda ash exports. In 1992, 60 percent of total export sales was to this area, including Canada and Mexico (5 percent each; Figure 12). Asia was the primary destination of U.S. soda ash exports, representing 43 percent of total foreign shipments. Japan and the Republic of Korea were the major importers in 1992. Some of the Pacific Rim countries, such as Australia, Japan, and the Republic of Korea, produced synthetic soda ash, which competed with U.S. exports. In 1987, partial or total foreign acquisition of U.S. producers began to occur. Foreign soda ash companies experiencing the higher operating economics of running synthetic operations saw the advantages of producing from natural resources in the United States.

Japanese and Korean companies are now joint venture partners with three of the U.S. soda ash companies. Japan's TOSOH Corporation and Asahi Glass Company own 24 percent and 20 percent, respectively, of General Cemical and Solvay Minerals, respectively, in Green River, Wyoming. Oriental Chemical Industries of Korea owns a 27-percent share of North American Chemical Company in California. Total foreign ownership of the U.S. soda ash industry stands at 49.4 percent. Only one of the six companies is exclusively U.S. owned—FMC Wyoming Corp.

As the demand for consumer products increases in many of the nations of the Pacific Rim, which have burgeoning population and rapidly developing economies, the long-term outlook for soda ash, borate compounds, and sodium sulfate supplied by the United States is very favorable. The region has been very important to the U.S. soda ash industry and will continue to be so into the 21st century.

The soda lakes of Oregon have the potential to supply a portion of the soda ash demand in the Pacific Northwest and possibly supply a portion of the soda ash, or value-added soda ash products, for export. More physical and economic evaluation of the Oregon soda lakes will be needed to determine the potential of the occurrences.

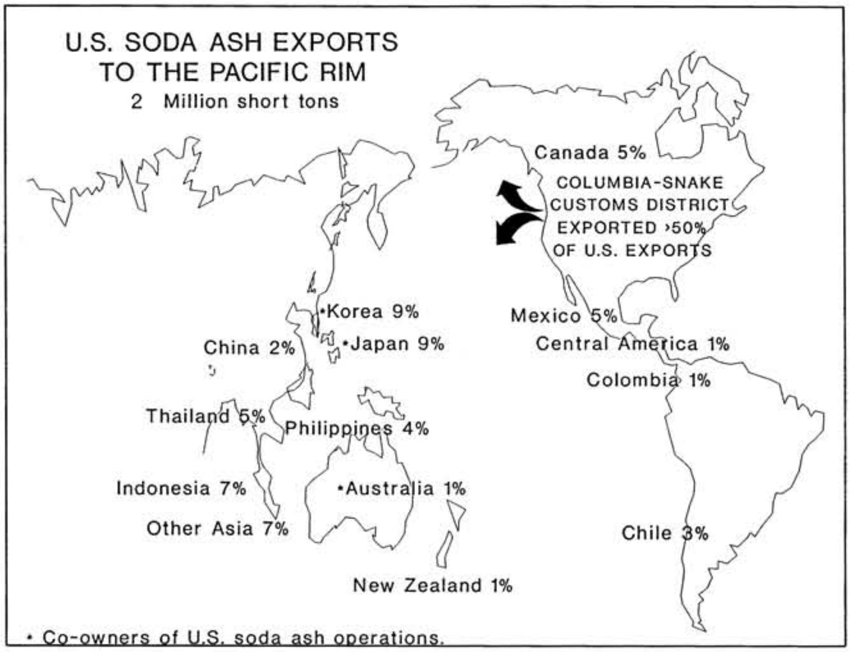

Figure 12. U.S. soda ash exports to the Pacific Rim.

ACKNOWLEDGMENTS

The authors are grateful to Larry Hill, Paisley, Oregon, for geographic information about the study area and the surrounding region, and especially for taking them to the thermal springs (Figure 2). John Withers of Paisley, provided historical background, and John Cremin of Lakeview and Harold J. Dyke of Adel, Oregon, provided historical and technical information on the Tenmile (Sundown) limestone claim group. Steven Carpenter, Robert Deal, and Robert B. Kistler of U.S. Borax, Los Angeles, California, Gail Moulton of North American Chemical Corporation, Trona, California, and Dwight Harris of Clayton, Washington, contributed information on evaporite mineral commodities. Rex Mckee and Jerry Gess, Weyerhaeuser Corporation, Longview and Tacoma, Washington, provided information on wood and paper processing.

Ronald Geitgey, Oregon Department of Geology and Mineral Industries, Portland, and Dennis Simontacchi, U.S. Bureau of Land Management, Lakeview, offered important geologic, historical, and logistical advice. Kent Keller, Washington State University, and Walter Ficklin and Alan Driscoe, USGS, Lakewood, Colorado, provided information on ground-water geochemistry. USGS personnel A.S. Van Denburgh, Reno, Nevada, and G.I. Smith, Menlo Park, California, provided information on the geology and geochemistry of closed-basin lakes. Gerilyn S. Soregham, USGS, and Spencee L. Willett, USBM, made important contributions throughout the field portions of this study.

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Expected tsunami amplitudes off the Tillamook County, Oregon, coast following a major Cascadia subduction zone earthquake

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As evidence accumulates indicating that the Cascadia subduction zone has produced major earthquakes and that at least some of the earthquakes were followed by large tsunamis (e.g., Atwater and Yamaguchi, 1991; Atwater, 1992), emergency planners along the Pacific Northwest coast have been trying to get an idea of how large a wave can be expected. Will it be 1 m, 10 m, or 100 m high?

One method of estimating the potential wave height is through numerical modeling of the earthquake source and tsunami propagation. Given a hypothetical set of earthquake source parameters, the sea-floor displacement can be computed. This displacement produces the sea-level perturbation that provides the impetus for a tsunami.

Whitmore (1993) computed wave amplitudes and currents at 131 sites along the North American coast for three hypothetical Cascadia subduction zone earthquakes. Here, the same tsunami modeling technique is used as in that study, and eight additional sites in Tillamook County, Oregon, are examined. The three earthquakes modeled in the original study were $M_W = 8.8$, 8.5, and 7.8. In this study only the magnitude 8.8 quake, which ruptures from the South Gorda plate to the subduction zone bend off the Washington coast (Weaver and Shedlock, 1989), is examined as that produced the largest tsunami along the Oregon coast. The tsunami model used here, described by Kowalik and Whitmore (1991), can determine the tsunami amplitude near the coast. The inundation level or runup of the tsunami is not computed. Amplitude can be thought of as the water column height over mean sea level at a point near the coast. Runup, though, is the vertical elevation which the tsunami reaches as it inundates the shore. Runup elevation often varies from the wave amplitude. Factors such as the beach slope, wave period, and beach roughness cause the runup to be higher or lower than the wave amplitude near the coast.

The fault parameters for the $M_W = 8.8$ earthquake are moment = 2.0E29 dyne-cm, strike = 358°, dip = 13°, slip = 90°, length = 650 km, width = 80 km, and fault bottom depth = 20 km. These were taken from studies of the Cascadia subduction zone by Spence and others (1985), Weaver and Baker (1988), Weaver and Shedlock (1989), and Savage and others (1991) and are explained further in Whitmore (1993). Static sea-floor displacement is computed from these parameters by dislocation formulae (Okada, 1985) and is

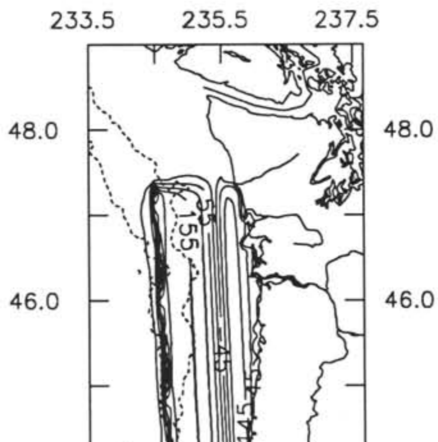

Figure 1. Vertical sea-floor displacement computed for $M_W = 8.8$ earthquake. Contour interval is 0.5 m. Maximum uplift is 3.7 m, while maximum subsidence near coast is 1.8 m. Dashed lines are bathymetric contours with a 1,000-m increment.

shown in Figure 1. This is a typical subduction-zone, underthrusting pattern with uplift seaward of the trench and subsidence toward the continent. Maximum uplift is near 3.7 m, and subsidence along the coast is up to 1.8 m. The computed subsidence compares well with paleoseismic studies which indicate coseismic subsidence of 1.0–1.5 m along the northern Oregon coast (Darienzo and Peterson, 1990).

The nonlinear, shallow-water equations of motion and continuity equation are used to model the tsunami, given the initial sea-level configuration defined by sea-floor displacement. Friction is accounted for in shallow water (i.e., continental-shelf depths). An explicit-in-time finite difference technique is used to solve the equations. This finite differ-

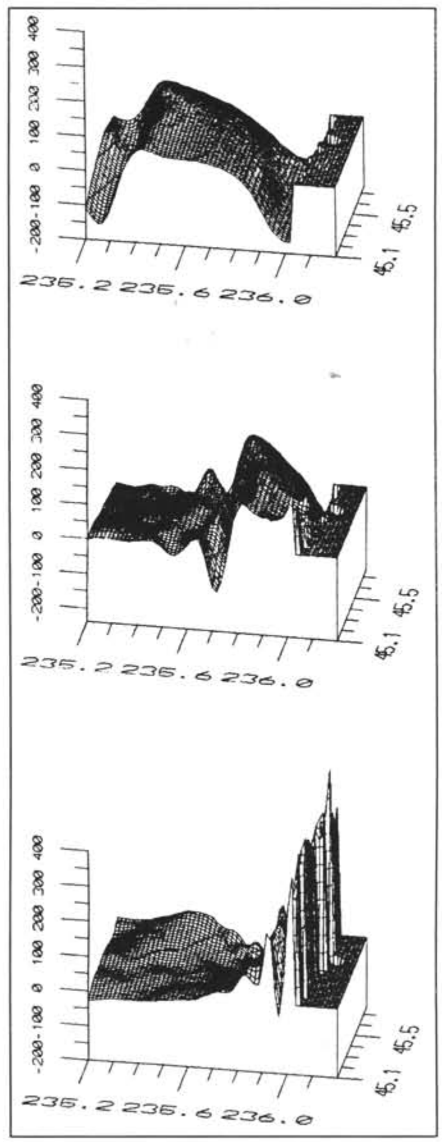

Figure 2. Time slices of the tsunami impinging on the Tillamook County coast at 10, 20, and 30 minutes after generation. Vertical scale is greatly exaggerated.

ence technique and the basic equations are explained in greater detail in Kowalik and Whitmore (1991). Briefly, the model computes a new north/south velocity, east/west velocity, and sea level at each grid point based on the old velocities and sea level every 11 seconds. This produces a "motion picture" of the wave with 11 seconds between frames. Figure 2 shows the tsunami as it moves to-

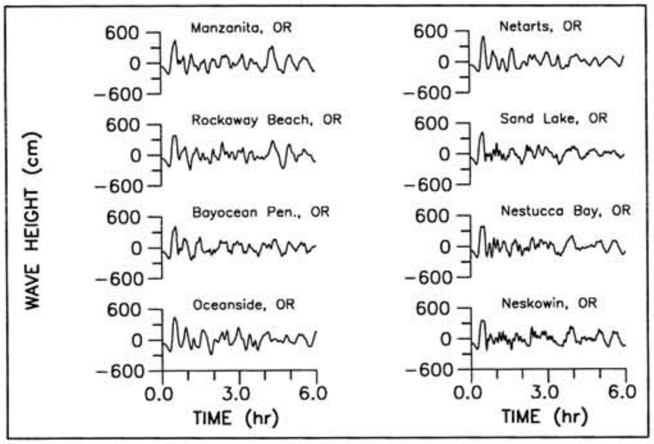

Figure 3. Modeled tsunamis at eight sites in Tillamook County, Oregon (locations shown in Figure 4 and Table 1).

Table 1. *Maximum modeled tsunami amplitudes along the coast of Tillamook County, Oregon*

Site	Lat (°N.)	Long (°W.)	Amplitude (m)
Manzanita	45.72	123.95	5.01
Rockaway Beach	45.62	123.97	4.45
Bayocean Peninsula	45.53	123.97	4.71
Oceanside	45.45	123.97	5.08
Netarts	45.43	123.95	5.53
Sand Lake	45.28	123.98	4.85
Nestucca Bay	45.18	123.98	4.67
Neskowin	45.12	124.00	4.35

ward the Oregon coast. The tsunami inundates the shore when the coast is reached. The model used here, though, does not account for this inundation. Pure reflection is assumed at the coast.

Shuto and others (1985) showed that 10 to 20 grid points per tsunami wavelength are necessary to accurately reproduce a wave numerically. This is accomplished here by using an edited version of the NOAA ETOPO5 five-minute bathymetry grid over the open ocean and a more detailed one-minute grid over the continental shelf where wavelengths decrease. At 45°N., a 1′ x 1′ grid has a spacing of approximately 1.3 km x 1.8 km. The two grids dynamically interact with each other at the five-minute to one-minute boundary. Some places along the coast such as within Tillamook Bay require higher detail than provided in the one-minute grid. This model can be considered accurate only along the outer coast, where one minute accurately defines the coastline and bathymetries.

Modeled tsunamis at eight sites along the Tillamook County coast are shown in Figure 3. In all cases, the initial wave is the largest of the tsunami series, although significant waves continue for over six hours. The first wave arrives about 23 minutes after the earthquake and is preceded by a recession. The time between successive crests varies from less than eight minutes to over an hour. The maximum zero-to-peak amplitude at these eight sites is 5.53 m at Netarts. This amplitude includes apparent amplitude due to subsidence at the site. Table 1 and Figure 4 summarize the maximum zero-to-peak amplitudes inclusive of local subsidence.

Several potential sources of error could modify the computed tsunami amplitude. The main factors controlling amplitude are size, configuration, and location of the source. Here the source is a simple planar fault with uniform slip. Other complexities such as submarine landslides, secondary faulting, nonuniform slip, faulting through the sedi-

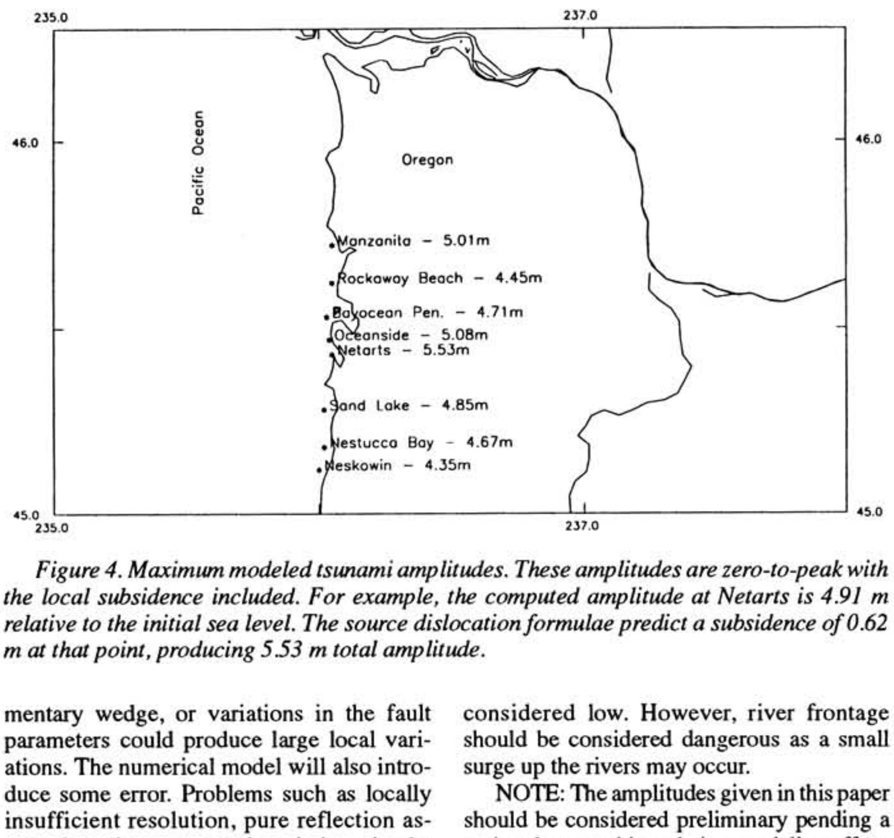

Figure 4. Maximum modeled tsunami amplitudes. These amplitudes are zero-to-peak with the local subsidence included. For example, the computed amplitude at Netarts is 4.91 m relative to the initial sea level. The source dislocation formulae predict a subsidence of 0.62 m at that point, producing 5.53 m total amplitude.

mentary wedge, or variations in the fault parameters could produce large local variations. The numerical model will also introduce some error. Problems such as locally insufficient resolution, pure reflection assumed at the coast, and variations in the tsunami from the assumed shallow-water wave behavior can cause differences between an actual tsunami and a model. Even with these possible sources of error, the results computed here should give planners along the coast a good ballpark figure.

The largest population center along this coast is Tillamook. The tsunami could not be accurately modeled at Tillamook due to the narrow entrance to Tillamook Bay and the bay's extensive mud flats. Considering that there are 2 mi of land and over 1 mi of mud flats at low tide between Tillamook and the bay, the tsunami danger at Tillamook can be considered low. However, river frontage should be considered dangerous as a small surge up the rivers may occur.

NOTE: The amplitudes given in this paper should be considered preliminary pending a national tsunami inundation modeling effort.

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Columbia stopped flowing in 1872!

Reprinted, with permission, from The Oregon Scientist, *v. 7, no. 1 (Spring 1994), p. 11.*

This report from *Best of the Old Northwest* [1980, Paddlewheel Press, P.O. Box 230220, Tigard, Oregon 97281], by Marge Davenport, is a collection of stories gathered from family records, old books, and papers from early days in the Northwest. Since there were no seismographs and probably no geologists in the Northwest in those early times, documentation of catastrophic events is difficult.

Suddenly, in 1872, the Columbia River stopped flowing! It was a quiet, calm night when the big earthquake hit the North Cascades. To the few residents, the travelers, and the Indians in the area, it seemed that the world was coming to an end.

The ground rocked and shook as if it was going to buck the few little cabins of the pioneers off the face of the earth. Trees swayed and snapped. Dogs howled, and the screams of terrified Indians echoed through their camps. A family near where the town of Entiat, Washington, would be founded testified in family records to the severity of the quake. The rumbling, roaring noise that accompanied the quake was deafening, they said.

Then, just as the quake began to subside and the noise stopped, there was a deafening roar, as if the surrounding mountains were collapsing.

Indeed, that was exactly what was happening. The mountain just north of the family's cabin, composed of granite interlaced with layers of volcanic ash, had split in half, and millions of tons of rocks and earth crashed thousands of feet below into the mighty Columbia River — to become an earth dam blocking its flow!

Because there were few residents in the area and because those who had settled there lived in small frame wooden buildings, no casualties were recorded the night of the big quake, but many strange things were reported.

When Indian women went to the river to get water the next morning from their camp near Wenatchee, they found the river had dried up and vanished.

A Yakima pioneer said two large cracks had opened up along a ridge east of the Columbia River, and oil was pouring out of the cracks and running down the mountain.

At Lake Wenatchee, where a pack train carrying supplies to a railroad survey party was camped, the packers reported huge boulders rumbled down Dirty Face Mountain and plunged into the lake.

At another spot, this near Chelan Landing, a huge geyser shot high into the air and continued to flow for months before its pressure was reduced and it became a mere spring. The Columbia River's flow continued to be dammed for several days, and everyone within traveling distance came to see the phenomenon. Fortunately, when the dam finally began to weaken and burst, those ahead of the wall of water that rushed down the valley were able to scurry to safety.

No effect at Portland?

At Portland, there is no recorded effect of the damming of the Columbia, although when the dam burst, it must have had some influence on the water level downstream. However, persons living along the river at that time built well back from the shores because of frequent flooding, and even a significant difference in water levels probably was not unusual.

Besides, the Snake, Yakima, John Day, Deschutes, and other large rivers join the Columbia before it reaches Portland, so the river probably just dropped slowly for several days and then surged as if from snow melt or cloudburst when the dam water was released.

Severe earthquakes were evidently more frequent in the Northwest in the 1800s, but because there were no recording instruments, because population was sparse, and communication was mostly by word of mouth, reports are vague as to their exact intensity. The next year after the North Cascades quake that dammed the Columbia River, a severe quake was reported at Fort Klamath to the south. This quake hit in the early morning and knocked people and animals to the ground.

An officer at the Fort, writing about the quake, said there were two hard shocks lasting about five to ten seconds each. Every pane of glass in windows at the Fort was broken, he said, but the frame wooden buildings did not suffer much damage. □

(DOGAMI PUBLICATIONS *continued from page 50)*

This database is provided in dBase III format (.DBF file) on one 3½-inch diskette. Introductory and explanatory discussions are contained in a text file.

This catalog is the first publicly available digital earthquake catalog for Oregon and presents Oregon's recorded earthquake history up to the most recent events. Over 15,000 earthquakes are included in the database, which was compiled from a variety of databases and catalogs covering the Pacific Northwest. Depending on the completeness of the source information, each earthquake record includes data on date and time of the event, location and depth of the epicenter, and magnitude and intensity of the shaking. Each record also contains information on the source of the data and, for many modern sources, on the quality of the determinations regarding location and magnitude of the earthquake.

When it is used in a database software program, this catalog can be searched to find earthquakes by size, time, geographic area, or any of the other details contained in each record.

Released April 1, 1994:

Mist Gas Field map, 1994 edition. Released as Open-File Report O-94-1. Price $8.

(Continued on page 70, DOGAMI PUBLICATIONS)

Geologic field work in Oregon and other parts of the the West since the 1930s

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, P.O. Box 751, Portland, OR 97207-0751

ABSTRACT

The author, during 20 years as a field geologist, examined nearly 200 chromite deposits, at least 350 other prospects and mines containing (or not containing) 14 different economic minerals and rocks, and mapped or assisted in mapping all or parts of 17 topographic quadrangles. Of the 14 in Oregon, seven were DOGAMI projects. One was in California and two in New Mexico.

For a young geologist with outdoor skills in the 1930s, field geology was rewarding professionally, personally, and even financially. This geologist now regrets the lowering prestige of this necessary and rewarding investigation of ground truth; he is glad he spent his most productive years in this stimulating and gratifying activity.

INTRODUCTION

This contribution to the history of West Coast geology, especially that in Oregon, summarizes recollections of some of my experiences in examining mineral prospects and mines and in mapping or assisting in the mapping of 17 quadrangles during 20 years as a field geologist from 1931 to 1951. These musings are more elaborately told in my autobiography *Bin Rock and Dump Rock* (1986)[1]. Fourteen of the 17 maps are in Oregon, seven were DOGAMI projects. One was in California, and two were in New Mexico.

The author as "field geologist" in 1931.

I mapped the geology of all or substantial parts of these quadrangles during periods ranging from 30 days to more than two years; I also did several stints of less than 30 days of mapping in other quadrangles. I also examined and reported on hundreds of mineral deposits in Oregon, as well as on many in Washington, California, Nevada, New Mexico, Arizona, and Pennsylvania.

Besides mapping, I had duties (and opportunities) to examine in these states prospects and mines that contained 14 different commodities: chromite (1938), tungsten, nickel, quicksilver, gold and silver (1939, 1941), tin (1942), manganese (1942), coal (1944, 1954), vanadium (1945), limestone (1946), perlite (1946), clay (1949), titanium (1956), and iron.

Some mapping in several other quadrangles generated no publications. These included mapping projects where I spent less than 30 days or occasions when I attended or supervised summer field camps in central Oregon, California, Pennsylvania, and New Mexico.

QUADRANGLES MAPPED

Quadrangles 1–4, during 1931: Parts of Camas, Bridal Veil, Bonneville Dam, and Hood River (1931, 1979, 1986, 1991).

A party of 11 graduate and undergraduate student geologists under the leadership of Dr. E.T. Hodge camped out in the Columbia River Gorge and in the northern Cascades of Oregon from early in June to late in September. Besides Hodge and Allen, other members of the party were Martin Meredith Sheets, Richard Bogue, Allen Griggs, Lloyd Ruff, Ernest McKitrick, Harold Fisk, Ed Thurston, Howard Handley, and (?) Derby.

The summer objective was to make a geologic reconnaissance of nearly 2,000 square miles in the Gorge and for 10 miles to the north and 30 miles to the south, including Mount Hood. The only day off was the Fourth of July, although each of us spent one day every week as camp tender and cook. The camp stove was a 1- by 3- by 5-foot ice freezing can, supported by rocks around the wood fire. We took down the tents and tables and changed camp every two or three weeks, occupying sites within the Gorge, near Government Camp, and farther south.

Each morning, Hodge would drop us off to follow a traverse from 5 to 15 miles long. Each evening, he expected us to be at a given pickup point by 5:00 p.m. Since completion of many traverses in nine hours was not always accomplished, all of the party except Allen Griggs and myself joined the OAN (out all night) Club.

I mapped in several parts of the area, with traverses around and across Mount Hood and as far south as Fish Creek Divide and Roaring River on the Clackamas. But most of my traverses consisted of climbing the Gorge walls at mile intervals to determine the elevation of the contact of the Columbia River basalt with the Troutdale gravels on the south side, and the basal contacts of the Columbia River basalt and the Eagle Creek Formation on the north side.

My most memorable traverse, however, was from Timberline on Mount Hood over the col above Illumination Rock, down Reid Glacier as far as the seracs of the icefall, over Yokum Ridge onto Sandy Glacier, then down Yokum Ridge to the road 10 miles to the west. It was long past the five o'clock deadline when I got to the meeting place, but Allen Griggs made a clandestine trip to pick me up and bring me back to camp. As a result of this traumatic experience I have never, during my entire professional career, sent a geologist out alone in rough country.

Each of us contributed to the others' maps, and three master's theses resulted from this work by the end of the next year. I compiled the geologic maps of the Gorge (1932); Martin Sheets described the petrology of the High Cascade andesites and Dick Bogue the petrology of the Columbia River basalts.

Twenty-five years later when I returned to Oregon to teach at Portland State College, the first thing I did was write a Gorge field trip guide for use by the class in physical geology during its fall term trip (up to 11 bus loads), a field trip that has taken place every year since 1955. After retirement, I enlarged this to the book *The Magnificent Gateway* (1979), the second edition of which (1984) is still in print in 1994.

Quadrangle 5, during 1933–4 and 1938: San Juan Bautista, California (1946).

When I went to Berkeley to work towards a Ph.D., it was suggested that I map the geology of the San Juan Bautista quadrangle, just east of Monterey Bay. I spent two full field seasons mapping this quadrangle, which is bisected by the San Andreas Fault and thus presents an entirely different stratigraphy on opposite sides of the rift. Since the map is about an area in California, this is not the place to describe the fascinating geology.

I was unable to complete this complicated map during my three years as a teaching assistant at Berkeley. So, in the spring of 1935,

[1] *All dates in parentheses refer to the primary publications listed at the end of this paper. Perhaps twice as many secondary publications resulting from these years of work are not cited.*

Field camp near Troutdale in the Columbia River Gorge during the summer of 1931.

I took a summer job at Crater Lake and then worked for two years prospecting for chromite before joining the Oregon Department of Geology and Mineral Industries (DOGAMI) in 1937. In 1944, I took leave to complete the San Juan Bautista map and write the Ph.D. dissertation (1946).

Quadrangle 6, during 1935: Small parts of Crater Lake (1936).

My former professor, Dr. Warren D. Smith, always meticulous in caring for his Oregon graduates, got me this first professional job at Crater Lake. Early in June, when we arrived at the Rim Village, the last mile of road was being cut through ten-foot snow drifts. Our quarters consisted of a platform with two facing tents, one to live in and one to sleep in, located about 300 yards southwest of the lodge. A faucet tap, an outdoor toilet, and a nearby washroom served as the naturalists' "Tent City."

The start of the memorable Mount Hood traverse of 1931. The "X" marks the gap the author was to cross.

The Ranger Naturalist staff consisted of four geologists, Carl R. Swartlow, Dr. Smith, myself, and Carl Dutton; botanist Elmer Applegate; biologist Ray Coopey; poet Ernest G. Moll; and photographer and artist L.H. Crawford. Our delegated and rotated duties consisted of (1) answering questions at the head of the Lake Trail and in the Sinnott Memorial, (2) conducting boat trips to Wizard Island and around the Lake, (3) conducting car caravan trips around the Lake, and (4) giving lectures after dinner in the lodge.

We each had one day of the week off; during those days I was able to map the location of 35 caves in and around the lake, describe the origin of numerous waterfalls, and map the geology of the domes exposed on the western and northern walls. Publication of a paper on the domes (1935) gave me full membership in Sigma Xi, and a diagram from that paper was used in Cotton's *Volcanic Landforms*. It was my first (and only) inclusion in a textbook.

Quadrangles 7–8, during 1935–6: Collier Butte and parts of Agness—Only Forest Service planimetrics available (1938).

At the end of the Crater Lake season, again through Dr. Smith's contacts, I was hired as field geologist for $150 per month and **all** expenses by C.E. Tuttle, CEO of Rustless Iron and Steel Corporation, to prospect for chromite on the West Coast, beginning in Curry County. Our base camp at Agness in 1935 was for nine months of the year accessible only by a 35-mile boat trip from Gold Beach.

We rented a log cabin on the south side of the Illinois River for $40 a month. It had two wood stoves, so we sawed and split several cords of wood to last us through the winter. Our water supply was through a pipe from a box 400 feet up the stream that ran alongside the house. A winter flood once tied the pipe in knots, while the roar on the "stream" kept us awake all night. We trapped numerous mice, and a polecat (spotted skunk) got into the cabin and had to be "coaxed" out.

To get our mail, we rowed across the Illinois River and then hiked for a mile, across the Rogue River suspension bridge (since then taken out by another flood), to the post office at Agness. We could order groceries from Gold Beach, which would be dumped on the river bar for us to pick up, half a mile downstream at the junction of the two rivers.

Since Oregon chromite is found in serpentine, peridotite, and dunite, for a year I mapped these rock bands while directing an eight-man prospecting crew, mostly from a tribe of Rogue River Indians headed by Walter Fry, who knew the country like the palm of his hand. I supplied the crew weekly from Agness by pack train, and reported on the claims they located. The crew took a day or so to construct each of three spike camps by cutting down a Port Orford cedar, splitting it into shakes, and building a small cabin.

Early in June of 1936, I sent a 30-page report to Tuttle, detailing the location, tonnage and grade of 67 small (less than 150 tons) chromite deposits in 92 claims. A week later a telegram from Tuttle said, "Fine work, but what shall I do?" I learned the hard way to put conclusions and recommendations **first** in all my reports.

As it turned out, all but one or two of the claims were too small and "too far from the railroad," so we moved our base to Grants Pass, where we set up a chemical laboratory to assay chromite samples, with Howard Stafford as chemist, and broadened the exploration to eventually report on more than 100 other chromite deposits in southern and central Oregon (1939), northern Washington (Twin Sisters), and in California as far south as San Luis Obispo (1941).

During this period, Tuttle asked me to report on several tungsten deposits in Nevada and an interesting large "low-grade" nickel deposit near Sedro Wooley, Washington. Many years later I spent several weeks examining the iron deposits of Nevada.

Conducting boat trips around Crater Lake was one of the author's responsibilities in 1935.

The road to the lodge at Crater Lake in June 1935.

"Spike cabin" as used for spike camps by the author in 1936 in southwestern Oregon.

Picture postcard scene of 1935, near Agness in Curry County, where the Illinois and Rogue Rivers join.

Quadrangle 9, during 1937: Parts of Round Mountain (now Ochoco Reservoir)—On planimetric Forest Service maps (1940); and

Quadrangle 10, during 1938: Parts of Butte Falls—Map published by DOGAMI without text (1941):

During the first two years with DOGAMI, I spent most of my time examining more than 200 prospects and mines in Baker County for DOGAMI Bulletin 14-A, the first of the Metal Mines Handbook series (1939). I was borrowed several times, however, to help with mapping in progress in other parts of the state. Wayne Lowell and I mapped for several weeks in the area northeast of Ochoco Reservoir (1940). The area was nearly all Clarno Formation and could be mapped only by locating widely scattered outcrops by traverses through the forest with Brunton compass and a 200-foot chain.

I also mapped for several weeks under W.D. Wilkinson in the Butte Falls quadrangle (1941) northeast of Medford. The rocks of this area were mostly composed of Western Cascades volcanics (we called the volcanic breccias the "Crud Formation"). It was another difficult area to delineate at that time.

Quadrangles 11–14, during 1938–39: Substantial parts of Enterprise, Eagle Cap, Joseph, Cornucopia—Only forest service maps with a 500-foot contour interval were available at that time (1941, 1975).

My first important mapping project for DOGAMI was reconnaissance of the Northern Wallowa Mountains, under Dr. Warren D. Smith. The crew of nine consisted of Dr. Smith, Ray Treasher, myself, Lloyd Ruff, Wayne Lowell, Herb Harper, Wilbur Greenup, Jim Weber, and Ray Huffaker.

The Wallowa Mountains have a relief of nearly a mile and a half, with elevations from less than 4,000 to more than 11,000 feet. To reach areas far from the roads, two of us would hike in with a pack horse and set up a spike camp. It usually took until noon to climb from camp to the top of the ridges.

The area includes most of the Cretaceous Wallowa Batholith, which intrudes Permian to Upper Triassic greenstone, siltstone, and limestone that have been folded into tight northeast-trending folds. The older rocks, now considered to be part of the Wrangellia Terrane, are overlapped on all sides by Columbia River basalt. Twenty-four glaciers, several of them more than 20 miles long, once cut the deep valleys that radiate out from the high peaks in the center of the range (1975).

Upon return to Portland late in August, we were able to patch together and publish within 90 days a preliminary colored map (1938) with a 16-page description. A few of us did further field work next summer, and the completed study was published as Bulletin 12 (1941).

During the early 1940s, I examined quicksilver deposits in the Ochoco and Maury Mountains and helped complete the second part of the Metal Mines Handbook, Bulletin 14-B (1941). I contributed to a bulletin on manganese in Oregon (1942) and sampled and mapped the geology of a reported tin deposit at Glass Buttes (1942), which turned out to be an elaborate hoax.

Quadrangle 15, during 1942–3: Substantial parts of Coos Bay (1944).

Ewart Baldwin, Ralph Mason, and I started remapping the Coos Bay quadrangle early in 1942. Besides measuring and subdividing the geologic formations and making large-scale topographic maps of several mine areas, we cleaned outcrops and measured thicknesses of numerous coal prospects and old mines. Ralph Mason, as engineer, supervised the hand-drilling of several of the shallower deposits and estimated coal reserves. The result was the publication of DOGAMI Bulletin 27 (1944).

Since we worked through a normal wet winter, we wore loggers' "tin" pants and heavy canvas jackets in an attempt to keep dry. While making large-scale topographic maps of deposits with a planetable, we used machetes to slash our way through the brush to give us a view of the stadia rod. For planetable "paper," we used aluminum sheets from a multigraph machine.

During the late 1940s I worked out of the Portland office on several economic deposits in western Oregon, such as limestone (1946) and brick and tile (1949). However, a most interesting commodity at that time was perlite, which is a high-water-content obsidian that expands like popcorn in a rotary furnace to form a very lightweight and fluffy aggregate that can be used in plaster and cement blocks.

I mapped a perlite deposit (1946) that lay on the steep east slope of the Mutton Mountains above the west bank of the Deschutes River at Dant. Before doing the geology, I made a one-square-mile, large-scale topographic map by planetable, using the railroad as a baseline and numerous laths set up around the property for triangulation to give elevations. The deposit was later extensively mined, the "ore" being shipped to Portland for furnacing.

Quadrangle 16, during 1950: Capitan, New Mexico (1981).

In 1947, I went to Pennsylvania State College as associate professor and head of the summer field camp. During two years there, I was unable to do any significant field mapping, although the 60 students in my camp mapped and measured sections in the mountains south of State College. An attempt to spend the latter part of the summer in quadrangle mapping was stymied when the head of my geology department heard that I was trying to map and assigned two graduate students to map my quadrangle.

When I went in 1949 to the New Mexico Institute of Mines and Technology as professor and head of the geology department, I began mapping the Capitan quadrangle, located east of Carrizozo, New Mexico. During my seven-year stay at Socorro, I mapped there for parts of three summers but was unable to finish the project. I did write a guidebook (1981) of the Capitan area, which went through three editions.

Quadrangle 17, during 1953–4: Substantial parts of Tohatchi, New Mexico, and east edge of Fort Defiance, Arizona (1954, 1955).

In 1952, I transferred from the Institute to the Bureau of Mines, and one of my first projects was to help Robert Balk map for the Navajo Tribal Council the Fort Defiance and Tohatchi quadrangles on the reservation 40 miles northwest of Gallup, New Mexico. As it turned out, Balk mapped the Fort Defiance, and I did the Tohatchi quadrangle.

Since no planimetry or topography existed, we mapped and published the geology in color on air-photo mosaics, perhaps the first time they had been used that way, but well adapted for use by the tribes. You could spot your location to the nearest pine tree or juniper bush!

Besides mapping this area, John Schilling and I measured with planetable more than 20,000 feet in eight different stratigraphic sections of Cretaceous Mesa Verde intertonguing sandstones and shales. The result (1954) was my last significant publication of geologic quadrangle maps.

CONCLUSION

Field geology during the 1930s may well have required more outdoor skills and adaptability than it does today, when 7½-minute topography, helicopter transportation, radio and satellite communication and location, and portable PC notebooks with modems are available.

Since geologic maps furnish basic information used in nearly all fields of geology, their construction and constant refinement by remapping (on larger scales and with newer hypotheses) should have higher priority than is frequently shown. There are still dozens of quadrangles that have never been mapped at all.

When I began field work, I discovered at once that I had use for skills I learned in winning 36 Merit Badges in Scouting (1990), such as hiking, cooking, camping, pioneering, surveying, first aid, canoeing, swimming, etc. My first professional job at Agness required each week that I make up and load (diamond hitch) two mules for a pack train.

Author carrying planetable equipment for mapping on the Deschutes River in 1928.

I was constantly challenged and stimulated by the need for problem solving, strategy, and logistics of field work, as well as by the actual deciphering of the intricacies of geology to make the geologic map. I found that my traverses were actually guided by the "multiple hypotheses" I generated. Field work gave me travel (and sight-seeing), hiking gave me exercise (and good health maintenance), and the many hours outdoors introduced me to flora and fauna I would never have seen or learned about otherwise.

At Crater Lake I learned to memorize Latin names of most of the plants and animals of the area. I had adventures with both bears and golden-mantled ground squirrels, there and elsewhere. I was once dive-bombed by a hummingbird (I must have sat down for lunch too near her nest?). I learned how to avoid rattlesnakes, wood ticks, mosquitoes, horseflies, and yellow-jacket nests (imagine what one could do to my pack train!). I learned how to work, talk, and deal with Indians, both in Curry County and in New Mexico. And perhaps best of all, I met all those other enthusiastic and interesting geologists!

All teachers should have a few years of field work before they meet their first classes. Such experiences gave me dozens of stories that I used for 28 years to perk up the students in my classes in general, economic, and regional geology. Such anecdotes, told with enthusiasm to illustrate a point, can make an ordinary teacher into an excellent teacher.

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Reclamation, regulation, and you — some basic questions and answers

The following text is from a recently published booklet by the Mined Land Reclamation Program, Oregon Department of Geology and Mineral Industries (MLR/DOGAMI), Albany, Oregon. The booklet is being distributed on request to all those interested in surface mine reclamation or in developing a mining operation. Anyone interested should contact MLR/DOGAMI at its Albany office, 1536 Queen Ave. SE, Albany, OR 97321, phone (503) 967-2039. *—ed.*

Just what is reclamation?

Reclamation is a multidisciplinary process of land treatment that minimizes adverse effects, such as water degradation, damage to aquatic or wildlife habitat, and flooding and erosion potential, that can result from mining operations.

Reclamation is not an activity that starts the day the mining ends. Instead, when done correctly it is a plan that is used throughout the entire mining operation. Then, when mining ends, the site is ready for completion of effective and acceptable reclamation.

Reclamation in Oregon means that after mining operations are over, a mine site must be made fit for other beneficial uses ("second uses") that are compatible with local zoning and surrounding land use activities and meet prevailing environmental and aesthetic standards as required in the mining permit.

Reclamation is a complex technical process. It involves ongoing attention and creative insight into engineering properties of material, mine configuration and development, the environment, economics, physical constraints of production, and sequence of mining activities.

The role of the Oregon Department of Geology and Mineral Industries (DOGAMI) is to oversee the sequencing and coordinating of this process to minimize the impacts to natural resources. The DOGAMI Mined Land Reclamation program is funded by the permit fees paid by mine operators.

Who must reclaim?

In Oregon, all mine sites that have greater than 5,000 cubic yards of production per year or that disturb more than one acre of land per year are subject to the reclamation requirements of DOGAMI. Also, if a mining operation disturbs a total of five acres over time, then reclamation is required. These regulations apply, in general, to commercial operations. Exemptions are made for on-site construction activities such as timber production and agriculture.

What about people?

Simply stated, those impacts of mining that affect people more than the engineering properties of the land or the environment are subject to considerations of land use. The land use category includes such factors as hours of operation, off-site noise, related road traffic, and impact on neighboring areas. These types of impact on people are not regulated by DOGAMI. Instead, they are regulated by local government through land use permitting processes.

What is the difference between reclamation and land use?

The simplest way to visualize the distinction between permitting for reclamation and permitting for land use is to picture yourself standing at the edge of a permit boundary. If you are looking at the mine site and thinking in terms of engineering properties, landslides, water, and other aspects of the natural environment, then you are thinking about aspects of reclamation. Those are the aspects of mining that are regulated by DOGAMI.

In deciding whether or not to issue a permit, DOGAMI works with other agencies and simply tells you, "If you are permitted to mine by local government, then your mine must meet these requirements."

On the other hand, the fundamental question asked by local government in considering an application to mine is simply, "Are you going to be allowed to mine, or aren't you?" Local government then makes a land use decision, as opposed to designing or approving a reclamation plan, as DOGAMI does.

How do state and local government agencies coordinate?

As the public and the prospective operator approach questions of whether to mine or not and how mining, if approved, is to proceed from a reclamation standpoint, the concerns of local government and DOGAMI are often interrelated. For example, if the public responds to local government hearings about a potential mine site by expressing concern about landslide potential, this concern must be communicated to DOGAMI. Likewise, when DOGAMI is considering the environmental and engineering aspects of a reclamation permit, it needs to know what is the second use that is being considered, how does this second use relate to local plans, and how does the public feel about such a second use.

Since 1991, the permit processes of DOGAMI and of local government have been properly constructed by law to allow the necessary coordination between the two types of permits. Before that time, coordination had been much more difficult.

When DOGAMI considers an application, it sends a copy to local government. Most commonly, local government asks for up to 165 days to work with DOGAMI and asks that DOGAMI not issue a permit until after local government has acted. Other coordination options are available, too, and local government has the opportunity to request them.

During this period of mutual consideration of applications, one for reclamation at the state level and the other for land use permit at the local level, several other natural-resource agencies are also routinely consulted before any permit is issued.

How much mining is there in Oregon?

Currently, DOGAMI has permits for approximately 800 active mine sites throughout the state. These include such operations as quarries, gravel pits, sand pits, mines for various types of industrial minerals, metal mines, and exploration sites. The sites range in size from one acre to tens or even hundreds of acres. Since 1972, approximately 3,000 acres have been reclaimed. Currently, 4,000 acres are under bond. Mining now covers less than one hundredth of one percent of the land in Oregon.

What does the future look like?

Mineral deposits do not occur everywhere. The choices of locations for possible mine sites to meet the needs of Oregon's growing population are dictated largely by nature. Challenges and potential conflicts related to mining will continue to need increased attention.

A trend that DOGAMI has noticed in recent years is toward increased complexity of permitting, particularly in areas affected by urban growth. As more and more of Oregon is urbanized, larger and larger mine sites are being contemplated in certain areas. At the same time, market areas and construction demands for materials from these sites are also expanding. Thus, we are going to see more complex regional sites in addition to the smaller, more local sites of the past.

Although planning and permitting of mining is done at the local level, the demand areas for some sites are expanding beyond the county boundaries in which the sites occur. This is placing a new challenge on the planning process in Oregon, particularly in the northern Willamette Valley. Dealing with these types of applications is going to be a growing challenge, both to government and to the public. New methods of decision-making may be required.

From a technical standpoint, the larger sizes of these new types of sites will require that DOGAMI give increasing attention to physical impacts on the environment, such as possible landslides and effects on ground water. More initial data will be required from the applicant. Monitoring and increased site visits may be required to assure that mining is proceeding as planned where it is permitted.

How does reclamation make sense?

It is important that, at a minimum, various laws, regulations, and requirements placed on mining be followed. In this way, the environment, safety, second beneficial use, and other concerns will be protected.

Reclamation securities or performance bonds are required to ensure performance of the reclamation plan requirements. Beyond this minimum level of reclamation and management, however, it is desirable to do more. We should cultivate a reclamation ethic. Where possible, creative use of the land should provide benefits above and beyond the requirements of the law.

For this reason, DOGAMI has implemented an awards program to recognize reclamation and mine operations that exceed law requirements. Other procedures are in place to facilitate reclamation "above the law." Visionary cooperation toward long- range goals can turn some mining into public landscape architecture at a profit.

With proper incentives, information, and a constructive working environment with the people and government, many operators can exceed the requirements of the law. Oregon mine operators, too, are concerned about the environment, second land use, and the cost-effective supply of our dwindling mineral resources to society. All Oregonians stand to gain with proper management of mines and their reclamation.

Reclaiming land to a second beneficial use can produce land with a greater value than it had originally. In some cases, productivity of farm land was increased through reclamation where lenses of porous gravels were removed to reduce irrigation demands. In other farm locations, the terrain was leveled to increase irrigation efficiency, or surface gravels were removed and separated from soil materials before the soil was replaced to reconstruct farmland.

Wetland protection is a concern to all Oregonians. The state has numerous operations where upland areas with shallow ground water have been converted to wetlands and lakes. This type of reclamation can actually begin while the sites are actively being mined. Increasing numbers of wildlife, particularly migratory waterfowl, use lakes and wetlands that have been created on mine sites because these sites provide excellent resting and foraging opportunities for wildlife. This type of reclamation helps create more diversified habitat than existed prior to mining. □

(DOGAMI PUBLICATIONS, *continued from page 64)*

The map of the Mist Gas Field in Columbia and Clatsop Counties has been updated and is accompanied by a production summary for 1993.

For the first time, the *Mist Gas Field Map* is available both as the usual paper copy and, on request, in digital form (price $25). It is offered in three different CAD formats (.DGN, .DWG, and .DXF), all on one 3½-inch high-density diskette formatted for DOS, for use by different software systems. Using a digitized version allows, for instance, add additional information or work with various scales and sections of the map.

Mist Gas Field production figures. Released as Open-File Report O–94–6. Price $5.

The cumulative report of past production at the Mist Gas Field during 1979–1992 is now available in a separate 40-page release.

Both the *Mist Gas Field Map* and the *Production Figures* are useful tools for administrators and planners as well as explorers and producers of natural gas.

Released April 6, 1994:

Preliminary geologic map of the Medford East, Medford West, Eagle Point, and Sams Valley quadrangles, Jackson County, Oregon, by Tom J. Wiley and James G. Smith. Released as Open-File Report O-93-13. Price $8.

The two-color map is printed on two sheets. An eight-page text contains a description of the rock units of the area, a geologic summary, a discussion of ground-water resources, mineral resources, and data tables with geochemical analyses and descriptions of mines and prospects.

The rocks in the Medford area record the 200-million-year geologic history of the region. Most of the rocks found in the region are either sedimentary rocks that were originally deposited as sediments in ancient oceans and rivers or volcanic rocks. Some have been metamorphosed; others have been mineralized to form precious-metal deposits. The region has been affected by landslides and faults, which are also shown on the map.

These maps continue the series of maps planned to aid regional planning in the Medford-Ashland area, which is experiencing rapid population growth. In addition to providing bedrock geology and mineral-resource data, landslides and faults are depicted in greater detail in this series than on previous maps. Earlier maps of this series are DOGAMI maps GMS–70 (1991) of the Boswell Mountain quadrangle and GMS–52 (1992) of the Shady Cove quadrangle.

The new publications are available over the counter, by mail, FAX, or phone from the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; and the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. □

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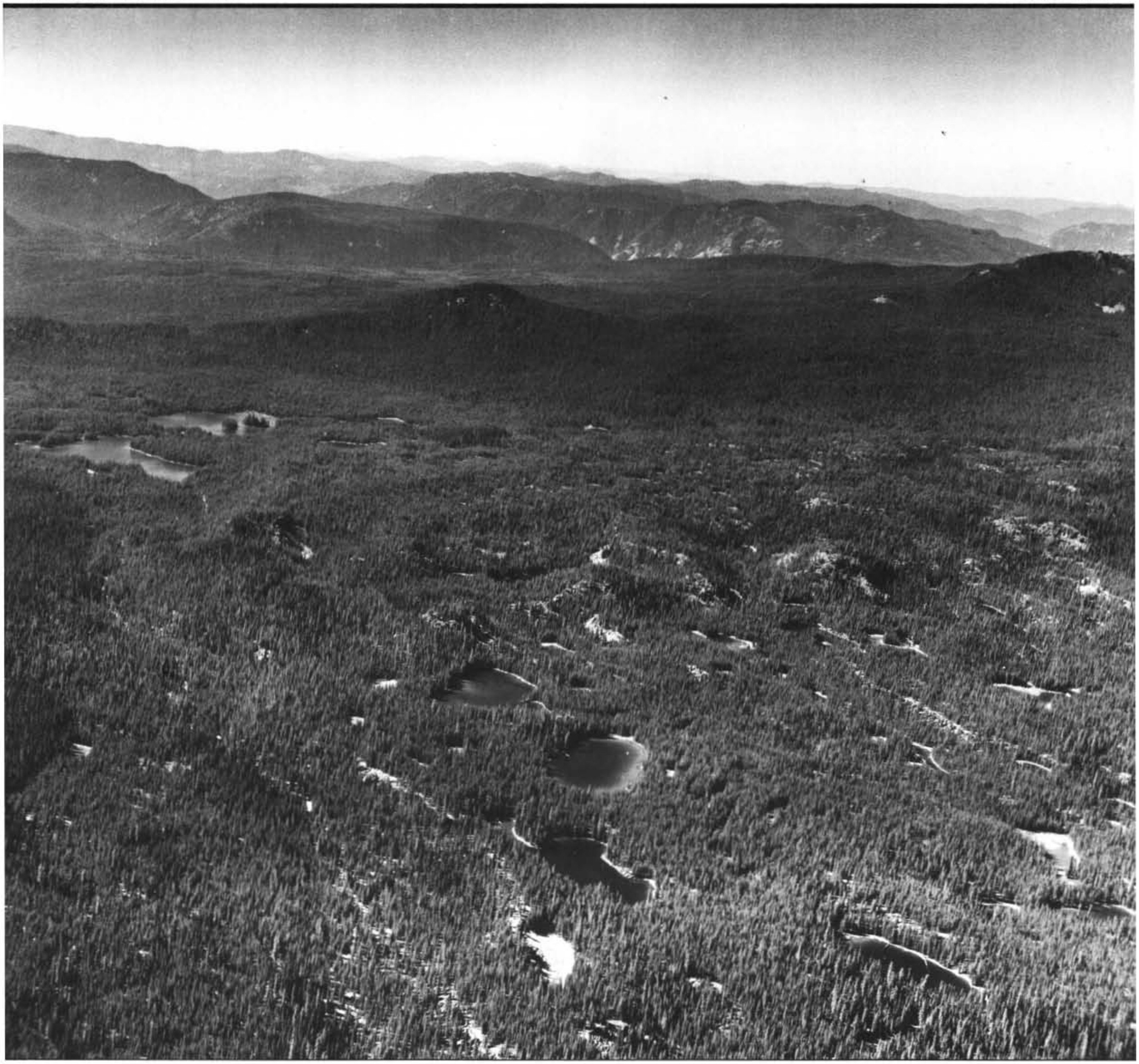

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OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 56, NUMBER 4 **JULY 1994**

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin.*)

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references). If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy **(from Macintosh systems, high-density diskette only)**. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be together at the end of the text.

Style is generally that of U.S. Geological Survey publications. (See USGS *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).

Cover photo contest

What do you see? Where is it? —How well do you know Oregon?—Send your answer by mail or FAX to editor Klaus Neuendorf (address above) before the next issue is released. If you are correct, your name will be entered in a drawing for a one-year free subscription to *Oregon Geology*, applicable to your current subscription. If you are a subscriber and use your win as a gift to a new subscriber, we'll double the winnings: a free subscription for two years.

The photo is one of the many masterful aerial photographs taken by the late Leonard Delano of Portland and (hint, hint) shows a view to the northwest. Copyright photo courtesy of Delano Horizons, Inc. □

Ian Madin honored by Metro

Ian Madin of the Oregon Department of Geology and Mineral Industries (DOGAMI) received one of seven Regional Hazard Mitigation Awards presented by Metro (the Portland area regional government) on June 17, 1994, at the Disaster Preparedness Conference held at the Monarch Hotel in Portland.

Madin received his award for the development of the Portland earthquake hazards map project that provides the key link between geologic earthquake information and practical mitigation opportunities. According to Metro, "Mr. Madin has been instrumental in interpreting the evolving scientific information concerning the earthquake threat in the metropolitan area to the needs of a general, nontechnical audience."

Other awards were given to (1) the City of Gresham, for construction of the emergency operations center (EOC), which can serve as a model for other jurisdictions; (2) Ms. Sherry Grandy, Emergency Manager for the City of Beaverton and Tualatin Valley Fire and Rescue, for her championing of coordination and cooperation among regional emergency managers; (3) Holliday Park Plaza in northeast Portland, for retrofitting the 15-story retirement community building for seismic protection; (4) Mr. Roger McGarrigle, volunteer Chair of the Oregon Seismic Safety Policy Advisory Commission, for advancing the cause of hazard mitigation in both his professional capacity as a structural engineer and in his many volunteer activities; (5) the Oregon Trail Chapter of the American Red Cross, for consistent excellence in its work on hazard mitigation training and neighborhood-organization programs, and in its booklet *Before Disaster Strikes*; and (6) U.S. Bancorp, for voluntarily upgrading its downtown Portland Plaza Building to Zone 4 earthquake standards, rather than the required Zone 3 standards, and for building a new data facility in Gresham to higher-than-required seismic safety standards. □

Culbertson to chair DOGAMI Board of Governors

The Governing Board of the Oregon Department of Geology and Mineral Industries has elected Board member Ronald K. Culbertson of Myrtle Creek as Chair for a term of one year beginning in July. He served as Chair once before, in 1991–1992, during his first term as a member of the Board.

Culbertson has been serving on the Board since 1988. His appointment as a Board member was renewed by Governor Roberts in 1992 and will extend until mid-1996. □

Subscription rates to increase October 1

Oregon Geology must raise its prices to stay alive in a world where almost nothing is cheap and certainly nothing is getting cheaper. In fact, as a subscriber to journals you may have gotten used to paying more every time you renew these days. We hope for your understanding and will do our best to continue offering what is of interest to you in Oregon's geology in the manner to which you have become accustomed.

We also want to give you a chance to renew at the old prices. Remember that your renewal will go into effect only after your current subscription expires—there is no overlap and no loss. So we are letting you know **now** that, **effective October 1, 1994**, the price for a single issue of *Oregon Geology* will be $3, the subscription price for six issues (one year) will be $10, and the subscription price for 18 issues (three years) will be $22.

The September issue of *Oregon Geology* will be the last one to show the current prices. Use the renewal form on the back cover **now** and let us have your renewal **by October 1** at the old price! □

Hydrothermal alteration in the SUNEDCO 58–28 geothermal drill hole near Breitenbush Hot Springs, Oregon

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ABSTRACT

In 1981, a 2,457-m-deep geothermal exploration drill hole, designated SUNEDCO 58–28, was completed about 3 km southeast of Breitenbush Hot Springs near the High Cascade-Western Cascade boundary in northwestern Oregon. A non-equilibrium temperature of about 141°C was recorded at the bottom of the drill hole, but the actual bottom-hole temperature may be nearer 150°C. Cuttings from the drill hole consist mostly of tuffs and tuffaceous sedimentary rocks of the Oligocene and lower Miocene Breitenbush Tuff. Several lava flows and occasional intrusive intervals are interspersed within the volcaniclastic deposits. The late Tertiary volcanic and volcaniclastic drill cuttings contain at least 26 hydrothermal minerals. Of the seven zeolite minerals identified, laumontite and heulandite occur most frequently. Calcite was found throughout most of the drill hole, but siderite is rare. In the upper 2,000 m of the drill hole, smectite and celadonite are the predominant clay minerals with lesser amounts of sepiolite(?), mixed-layer chlorite-smectite, chlorite, and corrensite(?); below 2,000 m, illite and a serpentine-kaolinite mineral are the main clay minerals along with minor chlorite. Chalcedony and crystal fragments of quartz were found throughout the drill hole, whereas cristobalite was identified only in a single sample. Pyrite crystals and red iron-oxide staining occur in many of the examined samples, but chalcopyrite and magnetite were each found in a single drill-cutting specimen. Several samples contain traces of epidote, and a few specimens have colorless anhydrite crystal fragments. Garnet(?), which could not have formed under the present moderately low-temperature conditions, was tentatively identified in one specimen. Some of the pyrite, quartz and chalcedony and all of the epidote also appear to have formed in a previous geothermal system and were transported later to the site of the SUNEDCO 58–28 drill hole. Fluid inclusion studies suggest that the drill hole probably penetrated the same shallow aquifer that feeds the Breitenbush Hot Springs. A second aquifer with significantly higher salinity may occur near the bottom of the drill hole.

INTRODUCTION

The SUNEDCO 58–28 geothermal drill hole is located about 3 km southeast of Breitenbush Hot Springs (Figure 1) at an elevation of 899 m (Conrey and Sherrod, 1988), near the Western Cascade-High Cascade boundary in northwestern Oregon. Drilling of the 2,457-m-deep exploration hole by Sunoco Energy Development Company began on October 2, 1981, and was completed December 11, 1981 (A.F. Waibel, unpublished data, 1982). The maximum reported near-equilibrium temperature for the drill hole is 129.3°C at a depth of 1,715-m (Blackwell and others 1986; Blackwell and Baker, 1988). A Pruett Kuster Tool Survey non-equilibrium temperature of about 141°C was recorded at the drill-hole bottom (A.F. Waibel, unpublished data, 1982); however, Blackwell and Baker (1988) estimate that the actual bottom-hole temperature may have been 145°–150°C.

The upper ~100 m of the SUNEDCO 58–28 drill-hole cuttings consist of middle and upper Miocene basalt and basaltic andesite (Priest and others, 1987; Conrey and Sherrod, 1988). The remainder of the drill hole penetrated the volcanic and volcaniclastic deposits of the Breitenbush Tuff of Oligocene and early Miocene age (Priest and others, 1987; Sherrod and Conrey, 1988). In the SUNEDCO 58–28 drill hole, this formation consists predominantly of ash-flow tuffs (some welded), tuffaceous sedimentary rocks, and basaltic to andesitic lava flows. These units are intruded locally by minor basalt to diorite sills or dikes of the same age (Figure 2) (Priest and others, 1987; Conrey and Sherrod, 1988). Primary minerals (both phenocryst and groundmass) in most lava flows are plagioclase and magnetite crystals. Hornblende phenocrysts were observed in some of the lava flows, and A.F. Waibel (unpublished data, 1982) reports that accessory minerals in other flows consist of olivine or pyroxene crystals. The tuffs range from lithic- to crystal-rich; one crystal-rich tuff zone contains embayed subhedral to euhedral quartz crystals. Primary plagioclase was generally identified in these samples; magnetite occurs commonly, but other accessory mafic minerals either were not observed or were altered. One basaltic sill, included in the drill-cutting samples for this study, contains plagioclase, magnetite, and pyroxene (hypersthene?). Another dioritic intrusion contained primary plagioclase; no mafic minerals were identified, but reflections for chlorite in one X-ray diffraction (XRD) analysis suggest that they may be altered.

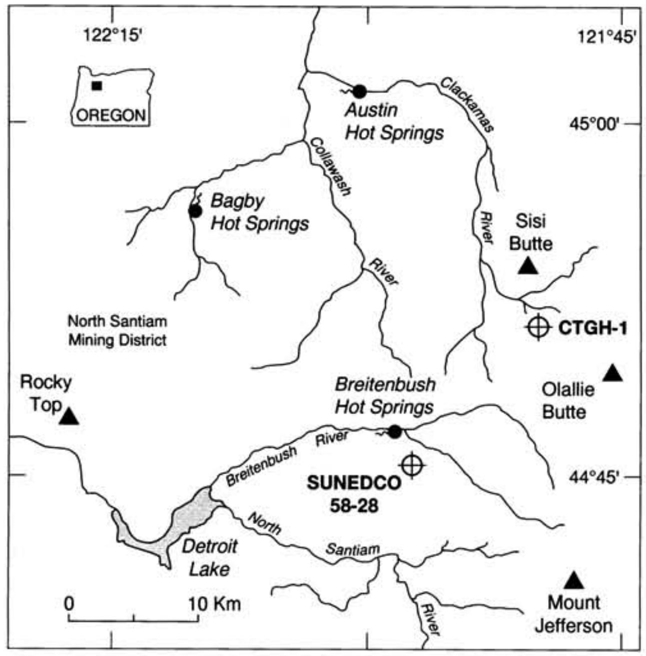


Figure 1. Map showing the location of geothermal drill hole SUNEDCO 58-28, as well as hot springs and the CTGH-1 geothermal exploration hole in the Breitenbush-Austin Hot Springs area of northern Oregon.

METHODS

The entire depth of the SUNEDCO 58–28 hole was rotary-drilled with drill-cutting samples collected for nearly all ~3-m intervals. Drill cuttings are useful in providing rock samples from deep within the earth that would not otherwise be available for examination; however, the samples frequently have been ground to a very small size (in many samples, the grains are <1 mm in diameter, although occasional samples contain fragments as large as ~1 cm), and details of crystal morphology, paragenesis, and lithological occurrence of the hydrothermal minerals often are obscured. Other problems that

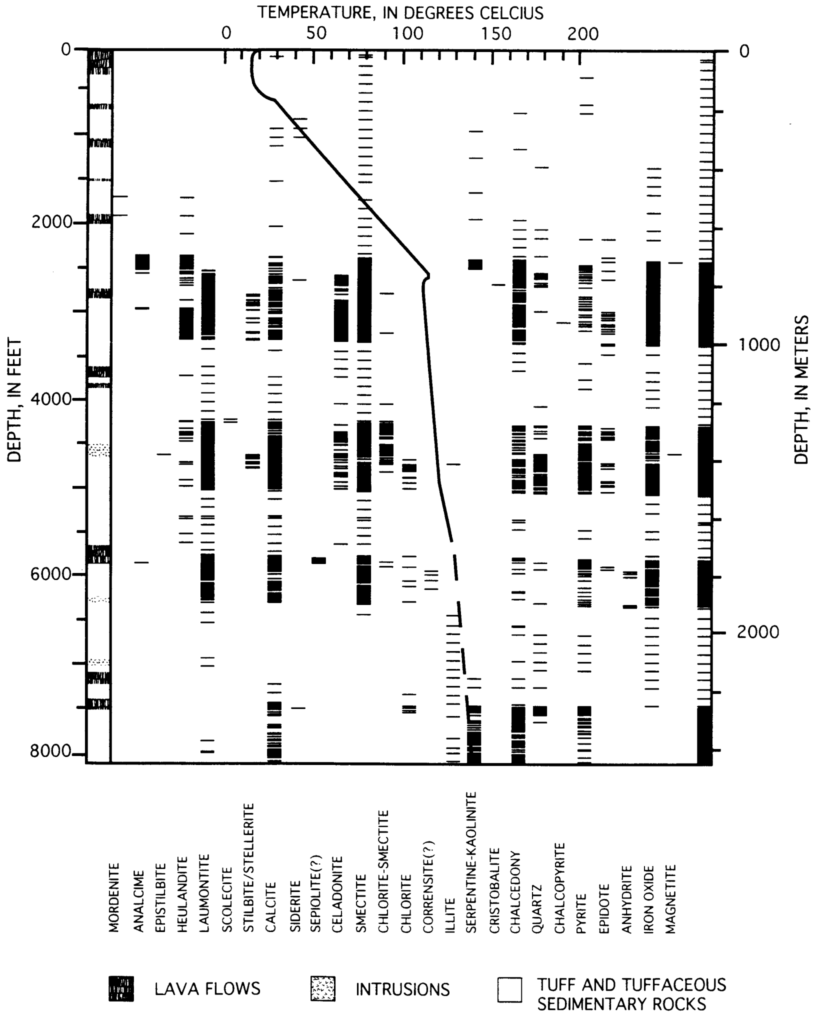


Figure 2. Distribution of hydrothermal minerals with depth in the SUNEDCO 58–28 drill hole. Left column shows a stratigraphic section of rock units penetrated by the drill hole (modified from Conrey and Sherrod, 1988). Right column shows the distribution of samples studied. Solid temperature curve is from Blackwell and others (1986); dashed part of the temperature curve connects the data from Blackwell and others with a bottom-temperature measurement of 141°C reported by A.F. Waibel (unpublished data, 1982).

hinder reliance upon drill cuttings for geologic information include contamination due to slumping of grains from higher in the well and mixing of drill chips from within each sample interval, so that precise delineation of lithologic boundaries is impossible.

Extensive lithologic descriptions of the drill-cutting samples and a comprehensive stratigraphic column for the drill hole were compiled by A.F. Waibel (unpublished data, 1982). Conrey and Sherrod (1988) published a generalized lithologic column for the SUNEDCO 58–28 hole based on the unpublished descriptions of A.F. Waibel. The stratigraphic column shown in Figure 2 is an abbreviated version of the Conrey and Sherrod (1988) compilation.

This study was undertaken primarily to obtain fluid inclusion homogenization temperature (T_h) data, using a Linkam[1] THM 600 heating/freezing stage and TMS 90 controller, from the lower half of the SUNEDCO 58–28 drill hole in order to determine how past temperatures compare with the present measured temperature profile shown in Figure 2. Some hydrothermal quartz was observed, but fluid-inclusion-bearing crystals were very sparse. Hydrothermal minerals most suitable for fluid-inclusion work were a few calcite and anhydrite crystal fragments. These broken crystals are very small, and the cleavage chips utilized in the study are either unpolished or polished only on one side. Only limited information on the salinity of the fluids trapped within the fluid inclusions was obtained from the unpolished samples. A few positive melting-point temperature measurements (T_m) (a clathrate or gas hydrate, which typically melts at positive temperatures, was not observed) for these low-salinity, low-temperature inclusions indicate that the fluids within some of them are metastable and do not provide reliable salinity estimates (Roedder, 1984). This was observed when the vapor bubble disappeared upon freezing and did not reappear by the time the last ice melted during warming of the fluid inclusion.

In order to locate appropriate minerals for fluid-inclusion study, it was necessary to examine many of the drill-cutting samples in great detail; accordingly, every ~3-m sample interval from four zones (Figure 2; extreme right column) was closely scrutinized and described. Throughout the remainder of the drill hole, cuttings from only ~30.5-m intervals were studied. Most mineral identifications were made by routine binocular and petrographic microscope methods. Using a Norelco X-ray unit and Cu-Kα radiation, 196 XRD analyses were obtained from selected samples that commonly contain clay or zeolite minerals. A few hydrothermal minerals were studied by a Cambridge Stereoscan 250 scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) in order to discern mineral paragenesis and semiquantitative chemical compositions. Electron microprobe analyses of some of the zeolite minerals were obtained from a JEOL JXA-8800L electron probe microanalyzer using a 25-μm beam diameter and 7.5-nÅ beam current.

HYDROTHERMAL MINERALOGY

Hydrothermal minerals in the SUNEDCO 58–28 drill-hole samples were listed by A.F. Waibel (unpublished data, 1982), and brief, generalized descriptions of the hydrothermal alteration were given in Conrey and Sherrod (1988) and Keith (1988). In the present investigation, about 42 percent (335) of the drill-hole samples was examined, and only a few previously unidentified hydrothermal minerals were recognized, mostly from XRD analyses. In the drill cuttings studied, several hydrothermal zeolite minerals and clay minerals were identified; other hydrothermal minerals include calcite, siderite, cristobalite, chalcedony, quartz, chalcopyrite, pyrite, epidote, anhydrite, magnetite, and iron oxide (Figure 2).

In addition to showing previously formed crystals of primary minerals and fragments of volcanic rocks, many of the tuff samples contain small lithic grains composed of hydrothermal chalcedony (± epidote) or grains with tiny pyrite crystals. This chalcedony and pyrite is obviously from a fossil hydrothermal system, but it is included in Figure 2 because at least some of it undoubtedly formed from geothermal activity that postdates the lithic tuffs. The very small grain size of other drill cuttings precludes distinguishing between minerals from possible late Tertiary fossil hydrothermal systems and those from subsequent hydrothermal systems, including the present active one.

[1]*Any use of trade, product, or firm names in this paper is for descriptive purposes only and does not imply endorsement by the U.S. Government.*

Zeolite minerals

Seven zeolite minerals (analcime, epistilbite, heulandite, laumontite, mordenite, scolecite, and stilbite/stellerite) have been identified in drill cuttings from the SUNEDCO 58–28 drill hole; laumontite and heulandite occur most frequently (Figure 2). Late Tertiary outcrops in the Breitenbush-Austin Hot Springs area contain many of these same hydrothermal zeolite minerals plus several additional zeolites. Formation temperatures for several hydrothermal zeolite minerals generally are thought to be about the same as the temperatures reported in studies of modern geothermal areas (summarized in Figure 2 of Keith, 1988). However, because of the Tertiary age of the rocks in the SUNEDCO 58–28 drill hole (Conrey and Sherrod, 1988), it is emphasized that favorable comparisons between measured temperatures at which zeolite minerals occur in this drill hole and the published formation temperatures is not unequivocal evidence that the minerals actually formed in the present thermal regime.

Analcime, $Na_{16}(Al_{16}Si_{32}O_{96}) \cdot 16H_2O$[2] — Analcime, in association with heulandite, laumontite, smectite(?), and halloysite, was identified in XRD analyses of several small greenish siliceous-appearing grains, light-gray lithic tuff fragments, and composite zeolite chips at 716–780 m. Analcime (plus laumontite, heulandite, and smectite) was found in two altered lithic tuff samples at 900 m. In addition, a single hornblende andesite sample from 1,787 m contains two isotropic, colorless crystal fragments with a refractive index of ~1.49 that probably are analcime; laumontite, calcite, chalcedony, pyrite, chlorite, and epidote(?) also are present in this sample.

Several outcrops of Oligocene and lower Miocene volcanic and volcaniclastic rocks in the Breitenbush-Austin Hot Springs area contain colorless, euhedral, trapezohedral analcime crystals lining vugs and fractures. An average electron microprobe analysis of one of these samples shows that the mineral is nearly a pure analcime containing essentially Na as the exchangeable cation (Table 1). Electron microprobe analyses of analcime from ~744-m depth in the SUNEDCO 58–28 drill hole also contain Na as the principal exchangeable cation. Some deviation from the stoichiometric formula given above is present in both outcrop and drill-hole analyses, but the balance errors for all analyses are within acceptable limits for zeolite minerals (Passaglia, 1970). These analyses indicate that the mineral is a nearly pure end member of the analcime-wairakite solid-solution series. Colorless, euhedral analcime crystals also line fractures and vesicles in drill core from geothermal drill hole CTGH–1, located about 14 km northeast of the SUNEDCO 58–28 drill hole (Figure 1); EDS semiquantitative chemical analyses of this analcime show that significant Ca is present in addition to Na, and the mineral is not a pure analcime end member (Bargar, 1990).

Analcime is a common mineral in geothermal areas, where, according to Kusakabe and others (1981), its formation appears to be favored by increasing the fluid pH and Na^+ concentration. In Iceland geothermal areas, analcime forms over a wide temperature range of about 70°C to near 300°C (Kristmannsdóttir and Tómasson, 1978). If analcime in the SUNEDCO 58–28 drill hole crystallized under present conditions, measured temperatures (~110°–130°C) indicate that the formation temperature was near the lower end of the Icelandic temperature range.

Epistilbite, $Ca_3(Al_6Si_{18}O_{48}) \cdot 16H_2O$ — An XRD analysis of white zeolite grains from the basaltic sill at 1,411 m contains reflections for epistilbite and quartz. Epistilbite is not a rare mineral, but it has not been frequently reported in the Oregon Cascade Range. Bargar and others (1993) identified epistilbite in a few geothermal test drill holes and one outcrop in Tertiary volcanic rocks of the Mount Hood area. Electron microprobe analyses of the Mount Hood epistilbite indicate that it is lower in Si and higher in Al and Ca than the stoichiometric formula. XRD analyses of samples from a few Tertiary outcrops in the Breitenbush-Austin Hot Springs area also contain reflections for epistilbite (Bargar, unpublished data).

Kristmansdóttir and Tómasson (1978) report that epistilbite in Iceland geothermal areas occurs at measured temperatures ranging from 80° to 170°C. The single occurrence of epistilbite in the SUNEDCO 58–28 drill hole was at a depth where the present-day temperature is near 120°C (Figure 2); thus it could be compatible with current thermal conditions.

Heulandite, $(Na,K)Ca_4(Al_9Si_{27}O_{72}) \cdot 24H_2O$ — Heulandite was identified by XRD from numerous samples throughout the middle portion of the drill hole (Figure 2). Many tuff grains contain heulandite that probably formed due to alteration of glass. Heulandite also occurs as open-space vesicle and microfracture fillings, where it frequently has a salmon to orange color. Other associated minerals identified in the XRD analyses are analcime, laumontite, smectite, mixed-layer chlorite-smectite, chlorite, celadonite, cristobalite, pyrite, chalcopyrite, and iron oxide. Only a few samples contained euhedral heulandite crystals as shown in Figure 3.

Electron microprobe analyses of one heulandite specimen from 939 m in the drill hole showed that it is Ca-rich heulandite (Table 1) rather than Na+K-rich clinoptilolite. This identification was confirmed by heating eight of the samples to 450°C for 24 h (Mumpton, 1960). After heating, the XRD 020 reflections for heulandite at ~9 Å disappeared. One sample appeared to have retained a very low XRD peak at ~8.6 Å, indicative of intermediate heulandite (Alietti, 1972). Both heulandite and intermediate heulandite have been identified from Tertiary outcrop samples in the Breitenbush-Austin Hot Springs area (Bargar, unpublished data). An average microprobe analysis for one late Tertiary heulandite specimen is given in Table 1; the analysis shows that the mineral consists almost entirely of Ca, Al, and Si, and is closer to the stoichiometric formula than are the analyses for heulandite from the SUNEDCO hole. Cation balance errors for all of the analyses fall within acceptable limits (Passaglia, 1970).

Figure 3. Scanning electron micrograph of randomly oriented, tabular to blocky, euhedral heulandite crystals from about 771 m.

[2]*Stoichiometric formulas after Gottardi and Galli (1985).*

Both heulandite and clinoptilolite were identified from vesicles, fractures, and between breccia fragments in late Tertiary basaltic drill-core samples from nearby geothermal well CTGH–1 (Bargar, 1988, 1990). The measured temperatures at the depths where heulandite in the SUNEDCO hole occurs range from 80°–130°C. These temperatures are within the range (<70° to ~170°C) for heulandite in Iceland geothermal areas (Kristmansdóttir and Tómasson, 1978). In contrast, clinoptilolite and heulandite occur at significantly lower temperatures (~30°–96°C) in the CTGH–1 drill hole (Bargar, 1990).

Laumontite, $Ca_4(Al_8Si_{16}O_{48}) \cdot 16H_2O$ — Soft, milky-white laumontite was seen in most samples studied between 768 m and 1,981 m in the SUNEDCO hole (Figure 2). Some samples from a depth below 2,000 m contain a few grains of laumontite that might have sloughed from higher in the drill hole. Laumontite is readily dehydrated to form the mineral leonhardite, which is designated as "only a variety" of laumontite (Gottardi and Galli, 1985). While leonhardite may occur in the drill-cutting samples from this drill hole, no attempt was made to distinguish between the two minerals, and only the name "laumontite" is used in this report. The presence of laumontite in whole-rock XRD analyses of several tuff samples suggests that some occurrences may have formed due to alteration of glass fragments or matrix. However, most laumontite occurs as euhedral crystals that formed in open spaces of fractures and vugs and between lithic fragments (Figure 4). Other hydrothermal minerals identified in association with laumontite in the drill hole samples are analcime, heulandite, calcite, siderite, quartz, pyrite,

Figure 4. Scanning electron micrograph of fractured to broken laumontite (L) crystals in association with earlier, euhedral quartz (Q) crystals from about 1,454 m. See also Figure 8.

Table 1. *Electron microprobe analyses of zeolite minerals from the SUNEDCO 58–28 drill hole and outcrops in the Breitenbush-Austin Hot Springs area. Reported outcrop analyses are averages of 5 analyses. — = not analyzed. Bal. error is determined by method of Passaglia (1970). (Continued on next page)*

Mineral	Analcime				Heulandite						Laumontite	
Sample no.	SUNEDCO 58–28 2440			80 COL-2040A	SUNEDCO58–28 3080					80 OGF-2076F	SUNEDCO 58–28 4230	
Analysis no.	1	2	3	1	1	2	3	4	5	1	1	2
	Weight percent oxides											
SiO_2	59.44	59.33	59.74	56.99	65.04	65.60	66.42	67.87	67.15	63.93	51.77	51.71
Al_2O_3	22.24	22.01	21.79	22.13	14.41	14.56	15.52	14.49	14.57	16.77	21.40	20.39
Fe_2O_3	0.10	0.02	0.07	0.01	0.11	0.07	0.00	0.14	0.03	0.00	0.00	0.00
MgO	0.00	0.03	0.00	0.01	0.02	0.03	0.02	0.02	0.02	0.00	0.00	0.03
MnO	0.03	0.02	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
CaO	0.17	0.15	0.13	0.00	6.81	6.83	7.35	6.89	7.19	8.77	11.79	10.98
SrO	0.11	0.15	0.12	—	0.28	0.24	0.33	0.21	0.27	—	0.19	0.23
BaO	0.07	0.01	0.00	—	0.25	0.15	0.18	0.15	0.19	—	0.00	0.01
Na_2O	14.32	13.59	13.99	13.24	0.52	0.41	0.55	0.55	0.55	0.08	0.02	0.14
K_2O	0.02	0.03	0.02	0.01	0.33	0.23	0.27	0.21	0.25	0.32	0.05	0.14
Total	96.50	95.34	95.87	92.39	87.78	88.13	90.64	90.53	90.22	89.87	85.23	83.64
	Number of atoms on the basis of											
	96 oxygens				72 oxygens						48 oxygens	
Si	33.09	33.29	33.37	32.96	28.56	28.60	28.27	28.78	28.65	27.53	16.12	16.37
Al	14.59	14.56	14.35	15.09	7.45	7.48	7.79	7.24	7.33	8.51	7.85	7.61
Fe	0.04	0.01	0.03	0.00	0.04	0.02	0.00	0.05	0.01	0.00	0.00	0.00
Mg	0.00	0.03	0.00	0.00	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.01
Mn	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.10	0.09	0.08	0.00	3.20	3.19	3.35	3.13	3.29	4.04	3.93	3.72
Sr	0.00	0.05	0.04	—	0.07	0.06	0.08	0.05	0.07	0.00	0.03	0.04
Ba	0.02	0.00	0.00	—	0.04	0.03	0.03	0.03	0.03	0.00	0.00	0.00
Na	15.46	14.78	15.15	14.85	0.44	0.35	0.45	0.45	0.46	0.07	0.01	0.09
K	0.01	0.02	0.01	0.01	0.19	0.13	0.15	0.11	0.14	0.18	0.02	0.06
Si+Al	47.68	47.85	47.72	48.05	36.01	36.09	36.06	36.03	35.98	36.04	23.97	23.97
$Si/Al+Fe^{3+}$	2.26	2.28	2.32	2.18	3.81	3.81	3.10	3.95	3.90	3.23	2.05	2.13
$Si/Si+Al+Fe^{3+}$	—	—	—	—	—	—	—	—	—	—	—	—
Bal. error	-6.99	-4.02	-6.62	1.54	2.67	6.06	3.63	4.00	-0.70	4.51	-1.49	-1.32

chalcopyrite, hematite, smectite, celadonite, and mixed-layer chlorite-smectite. SEM studies indicate that laumontite formed later than quartz, mixed-layer chlorite-smectite, and siderite and was deposited earlier than smectite and heulandite.

Laumontite is a very common hydrothermal mineral and has been found over a wide temperature range (43°–230°C) (Kristmannsdóttir and Tómasson, 1978; McCulloh and others, 1981) in many geothermal areas. The present-day temperature range at which laumontite was identified in the SUNEDCO hole is very narrow (110°–130°C).

Electron microprobe analyses of laumontite from about 1,289 m in the SUNEDCO hole showed that the mineral contains only small amounts of elements other than Ca, Al, and Si (Table 1). During related field studies of the Breitenbush-Austin Hot Springs area, laumontite was collected from several late Tertiary outcrops. Electron microprobe analyses of laumontite from two of the widely separated outcrops in this area (Table 1) are very similar to the SUNEDCO 58–28 analyses. Both drill-hole and outcrop analyses of laumontite do not quite match the stoichiometric formula given above; however, cation balance errors for all of the analyses are within acceptable limits (Passaglia, 1970).

Mordenite, $Na_3KCa_2(Al_8Si_{40}O_{96}) \cdot 28H_2O$ — XRD analyses of a few milky-white siliceous fragments from depths of 518 m and 579 m contain reflections for mordenite. These two samples are the only ones in which mordenite was identified; however, mordenite occurs in several late Tertiary outcrops in the Breitenbush-Austin Hot Springs area and is common in drill core from the lower part of the nearby drill hole CTGH–1 (Bargar, 1988, 1990). In these occurrences, mordenite is a late hydrothermal mineral deposited in open spaces of fractures and vugs together with heulandite and chalcedony.

In SUNEDCO 58–28, mordenite was found where the measured temperature is ~80°C. In Icelandic geothermal areas, mordenite is found over a temperature range of 80°–230°C (Kristmansdóttir and Tómasson, 1978); however, in drill hole CTGH–1, mordenite was identified at depths where present-day temperatures are 60°–96°C.

Scolecite, $Ca_8(Al_{16}Si_{24}O_{80}) \cdot 24H_2O$ — Two samples at 1,280 m and 1,289 m contain a few grains of hard, white, fibrous scolecite; laumontite and smectite occur in the same samples. Scolecite also has been found in a few late Tertiary outcrops in the Breitenbush-Austin Hot Springs area. The mineral is identified as scolecite (Ca-rich) because it exhibits inclined optical extinction; structurally similar mesolite (Na+Ca) and natrolite (Na-rich) both have parallel extinction. Electron microprobe analyses of scolecite from the Mount Hood area (Bargar and others, 1993) are consistent with the stoichiometric formula given above.

Ca-rich scolecite was reported from drill hole CTGH–1 (temperature is ~30°–40°C) (Bargar, 1990); however, subsequent electron microprobe analyses (Bargar, unpublished data) show that the mineral contains significant Na and is mesolite. The measured temperature at the depth where scolecite was found in the SUNEDCO hole is about 120°C. From their studies of Icelandic geothermal areas, Kristmannsdóttir and Tómasson (1978) reported scolecite (and mesolite) only from drill holes in low-temperature areas at <70°–100°C.

Stilbite / Stellerite,
$NaCa_4(Al_9Si_{27}O_{72}) \cdot 30H_2O$ / $Ca_4(Al_8Si_{28}O_{72}) \cdot 28H_2O$ — Crystal fragments of a colorless (sometimes white or orange iron-oxide stained), tabular to lamellar, soft zeolite mineral were observed

Table 1. *Electron microprobe analyses of zeolite minerals–(continued from previous page)*

Mineral	Laumontite					Stilbite/Stellerite						
Sample no.	SUNEDCO 58–28 4230			80COL-2033E	81 BP-2102C	SUNEDCO 58–28 3300					80 COL-3031I	81 FC-2052E
Analysis no.	3	4	5	1	1	1	2	3	4	5	1	1
	Weight percent oxides											
SiO_2	52.18	53.11	53.09	52.42	53.62	64.61	62.79	62.05	61.78	64.02	56.44	59.12
Al_2O_3	20.63	21.21	21.75	21.70	22.17	16.12	16.64	15.74	16.23	16.25	15.04	18.01
Fe_2O_3	0.00	0.00	0.02	0.03	0.00	0.05	0.04	0.00	0.04	0.00	0.00	0.00
MgO	0.00	0.01	0.00	0.02	0.00	0.02	0.01	0.01	0.02	0.02	0.01	0.01
MnO	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.01
CaO	11.07	11.45	11.82	10.93	11.38	7.71	7.76	7.67	7.75	7.89	7.64	8.36
SrO	0.12	0.10	0.26	—	—	0.40	0.45	0.49	0.56	0.40	—	—
BaO	0.07	0.10	0.01	—	—	0.37	0.61	0.45	0.59	0.35	—	—
Na_2O	0.19	0.17	0.13	0.18	0.31	0.49	0.43	0.40	0.40	0.45	0.56	1.02
K_2O	0.13	0.12	0.09	0.52	0.13	0.23	0.32	0.24	0.28	0.24	0.05	0.01
Total	84.39	86.27	87.17	85.80	87.61	90.00	89.06	87.06	87.66	89.62	79.74	86.54
	Number of atoms on the basis of											
	48 oxygens					72 oxygens						
Si	16.36	16.31	16.16	16.18	16.19	27.85	27.48	27.72	27.40	27.73	27.41	26.60
Al	7.63	7.68	7.81	7.90	7.89	8.19	8.58	8.29	8.49	8.30	8.61	9.55
Fe	0.00	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00
Mg	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.26	0.01	0.01	0.01
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	3.72	3.77	3.86	3.62	3.68	3.56	3.64	3.67	3.68	3.66	3.98	4.03
Sr	0.02	0.01	0.05	—	—	0.10	0.11	0.13	0.14	0.10	—	—
Ba	0.01	0.02	0.00	—	—	0.06	0.11	0.08	0.10	0.06	—	—
Na	0.12	0.10	0.08	0.11	0.18	0.41	0.37	0.35	0.34	0.38	0.53	0.89
K	0.05	0.05	0.04	0.20	0.05	0.06	0.18	0.14	0.16	0.13	0.03	0.01
Si+Al	23.99	23.98	23.97	24.08	24.07	36.03	36.07	36.01	35.89	36.03	36.02	36.15
$Si/Al+Fe^{3+}$	2.15	2.12	2.07	2.05	2.05	3.39	3.20	3.34	3.22	3.34	3.18	2.79
$Si/Si+Al+Fe^{3+}$	—	—	—	—	—	0.77	0.76	0.77	0.76	0.77	0.76	0.73
Bal. error	-0.57	-0.95	0.05	4.34	3.87	3.31	3.80	0.35	-4.50	1.44	0.97	6.46

in two zones: 844–1,009 m and 1,405–1,454 m (Figure 2). XRD analyses indicate that the mineral is either stilbite or structurally similar stellerite between which a complete solid-solution series exists (Passaglia and others, 1978). A few specimens are associated with hydrothermal quartz, laumontite, or dark-green clay (both smectite and mixed-layer chlorite-smectite). Occasional cuttings show thin veins filled with late, colorless, tabular, broken stilbite/stellerite crystals oriented perpendicular to earlier dark-green clay-lined margins.

Electron microprobe analyses of several stilbite/stellerite crystals from about 1,006 m are given in Table 1 along with stilbite/stellerite from late Tertiary outcrops in the Breitenbush-Austin Hot Springs area. The analyses listed in Table 1 show that Ca is the dominant cation, suggestive of stellerite rather than stilbite, but these two very similar minerals are distinguishable with confidence only by single-crystal XRD analysis (R.C. Erd, written communication, 1992), which was not attempted for any of these stilbite/stellerite specimens.

Stilbite/stellerite occurs in the SUNEDCO hole at present-day temperatures of about 110°C to 120°C. In Iceland, stilbite is found at 70°–170°C (Kristmannsdóttir and Tómasson, 1978).

Carbonate minerals

Calcite — Samples throughout the SUNEDCO hole contain soft, white, cloudy, or colorless calcite (Figure 2). It usually occurs as monomineralic crystal fragments; complete crystals or crystal clusters (Figure 5) are uncommon. Calcite is seldom associated with other hydrothermal minerals, only rarely with laumontite. Calcite commonly fills fractures, vesicles, and cavities between tuff breccia fragments in the Oligocene and lower Miocene rocks of the Breitenbush-Austin Hot Springs area, and presumably its occurrence is similar in the SUNEDCO hole. In contrast, drill hole CTGH–1 contains only traces of calcite, mainly in early Pliocene lava flows (Bargar, 1988, 1990).

Liquid-rich secondary(?) fluid inclusions (Figure 6) were observed in several colorless to cloudy calcite crystal fragments. These fragments were too small and fragile to polish, although it was

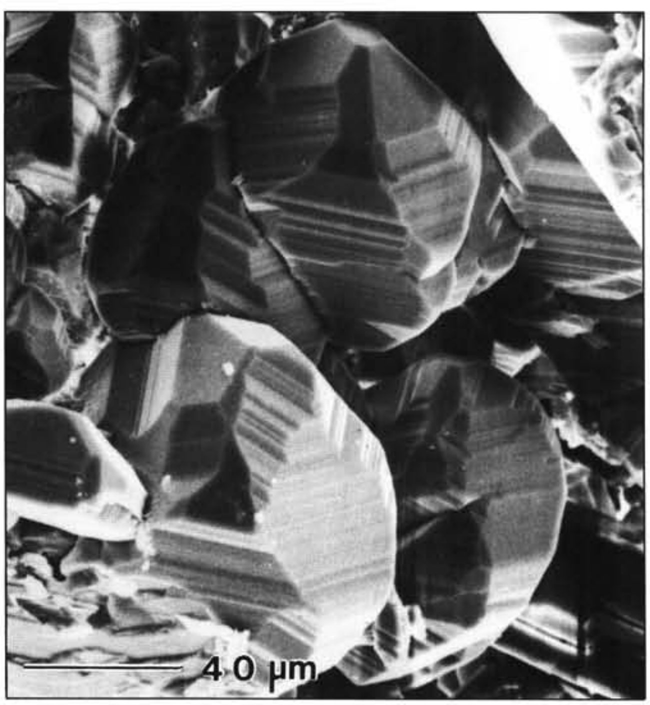


Figure 5. Scanning electron micrograph of twinned(?) calcite crystals from about 1,787 m.

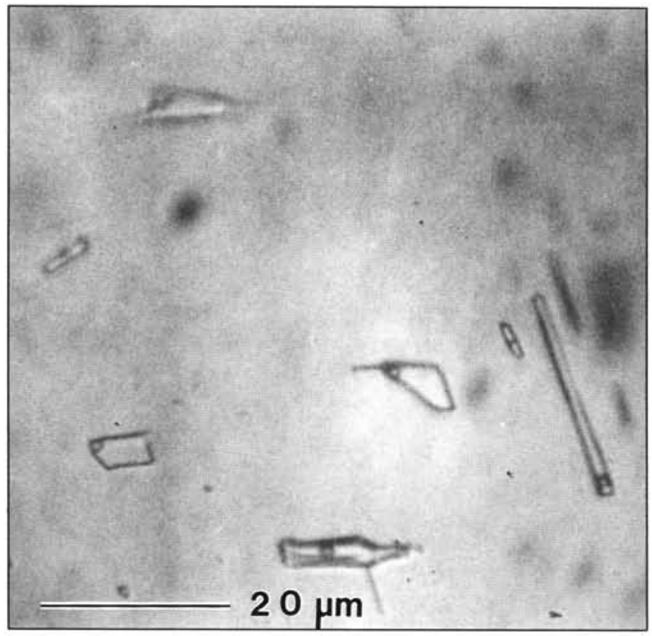


Figure 6. Photomicrograph of liquid-rich, secondary fluid inclusions in an unpolished calcite cleavage chip from about 1,470 m.

possible to obtain some fluid inclusion data. No melting-point temperatures (T_m) were obtained because, when the fluid inclusions were frozen, the tiny vapor bubbles disappeared and reappeared at temperatures as high as +3.9°C, indicating that the fluid inclusions were metastable and did not yield reliable salinity data (Roedder, 1984). However, 42 fluid inclusions in calcite from four sample depths yielded homogenization temperatures (T_h) ranging from 114° to 173°C (Table 2). Comparison of the fluid-inclusion T_h values with the measured temperatures in the SUNEDCO hole (Blackwell and others, 1986) in Figure 7 shows that (1) maximum fluid-inclusion T_h values record past temperatures that were at least as high as 152°C (one measurement is 173°C) and (2) minimum T_h measurements plot very close to the present-day temperatures at several depths within the drill hole. Close correspondence between minimum fluid-inclusion T_h values and present measured temperatures within other geothermal drill holes led Taguchi and others (1984) to conclude that minimum fluid-inclusion T_h can be used to estimate present-day temperatures within drill holes. Thus, fluid inclusions in calcite from this drill hole indicate that at least some of the trapped fluids are related to the present geothermal system. It may also be concluded that the geothermal system has cooled by about 35°C.

Siderite — Orange siderite was identified in five samples from 244 to 305 m, 796 m, and 2,280 m. SEM analysis of an open-space (fracture?) filling at 796 m (Figure 8) shows that colloform clusters of rhombic siderite crystals formed earlier than laumontite and smectite; an EDS analysis of this deposit detected the presence of Fe, Ca, and Mn. Siderite has not been found in outcrops examined in this area, but it occurs in a few drill-hole and outcrop samples in the Mount Hood area (Bargar and others, 1993) and in several geothermal core holes at Newberry volcano (Bargar and Keith, unpublished data). In U.S. Geological Survey (USGS) drill hole Newberry 2, siderite is found at temperatures ranging from 60° to 130°C (Keith and Bargar, 1988). Siderite occurs at present-day temperatures of 40°–140°C in the SUNEDCO hole.

Clay minerals

Ten clay minerals were identified in the SUNEDCO samples. The distribution of clay minerals shown in Figure 2 is based on XRD analyses of 124 clay-bearing specimens.

Table 2. *Fluid inclusion heating and freezing data for SUNEDCO 58–28 drill-hole specimens*

Sample depth (m)	Host mineral	Number of melting-point temperature measurements	Melting-point temperature T_m (°C)*	Salinity (wt. % NaCl equivalent)	Number of homogenization temperature measurements	Range of homogenization temperatures T_h (°C)*	Median homogenization temperature T_h (°C)
398	Quartz	10	0.0	0.0	**11**	232–274	**258**
882	Calcite	0	—	—	**6**	128–152	**147**
931	Calcite	0	—	—	**4**	118–123	**120**
1360	Calcite	1	-0.1	0.2	**13**	114–145	**127**
1470	Calcite	12	+2.2, +3.9	**	**19**	116–173	**127**
1794	Anhydrite	0	—	—	**12**	125–191	**130**
1910	Anhydrite	5	0.0, -0.5, +1.5	**	**13**	123–133	**128**
2347	Primary quartz	5	-1.6, -1.7, -2.0	2.7–3.4***	**24**	138–209	**167**
2408	Primary quartz	4	-2.4	4.0***	**11**	202–216	**210**

* Multiple calibration measurements, using synthetic fluid inclusions (Bodnar and Sterner, 1984) and chemical compounds with known melting-point temperatures recommended by Roedder (1984), suggest that the T_h measurements should be accurate to better than ±2.0°C and that the T_m values should be accurate to within ±0.2°C.

** Positive T_m values indicate metastability, and the fluid inclusions cannot be used for salinity calculations (Roedder, 1984).

*** Salinity values are not corrected for CO_2.

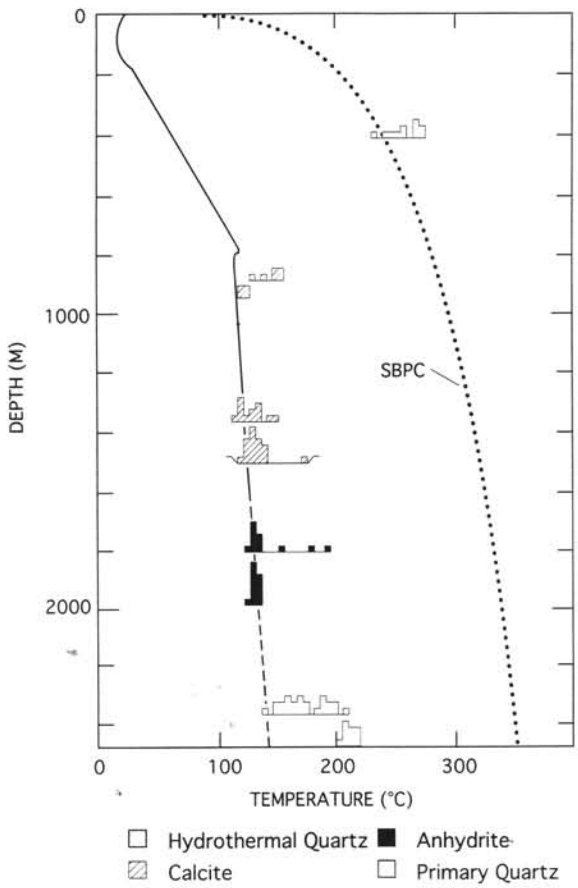


Figure 7. Depth versus homogenization temperatures for fluid inclusions in hydrothermal quartz, calcite, and anhydrite crystals, and primary quartz phenocrysts from drill hole SUNEDCO 58–28. Dotted curve labeled SBPC is a theoretical reference boiling point curve for pure water drawn to the ground surface. Solid curve shows a measured-temperature profile using data in Blackwell and others (1986); the continuing dashed line is an estimate of temperatures in the lower part of the drill hole based on a bottom-hole temperature of ~141°C given by A.F. Waibel (unpublished data, 1982). Individual T_h measurements, shown by different patterned boxes keyed to type of mineral analyzed, are plotted at 5°C intervals as histograms with sample depth as a baseline.

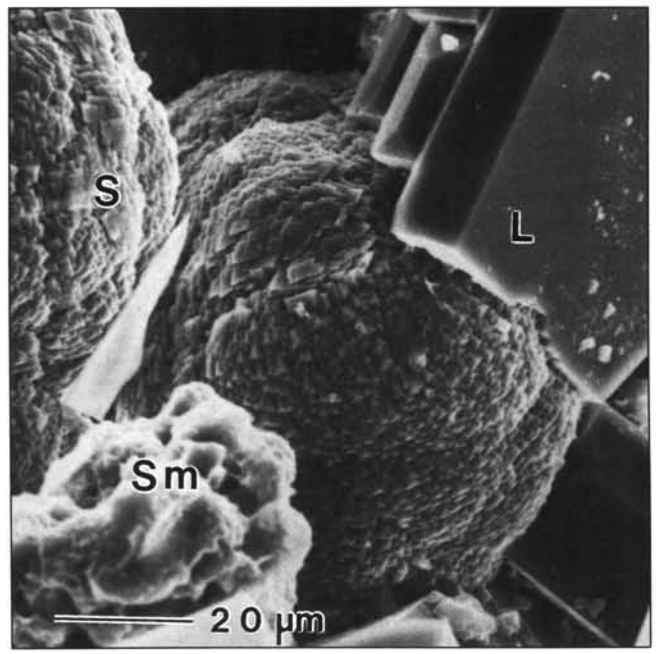
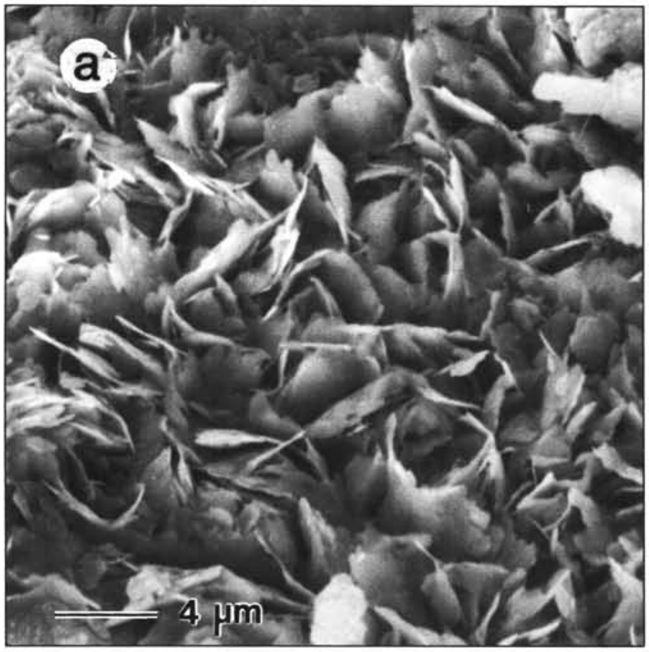
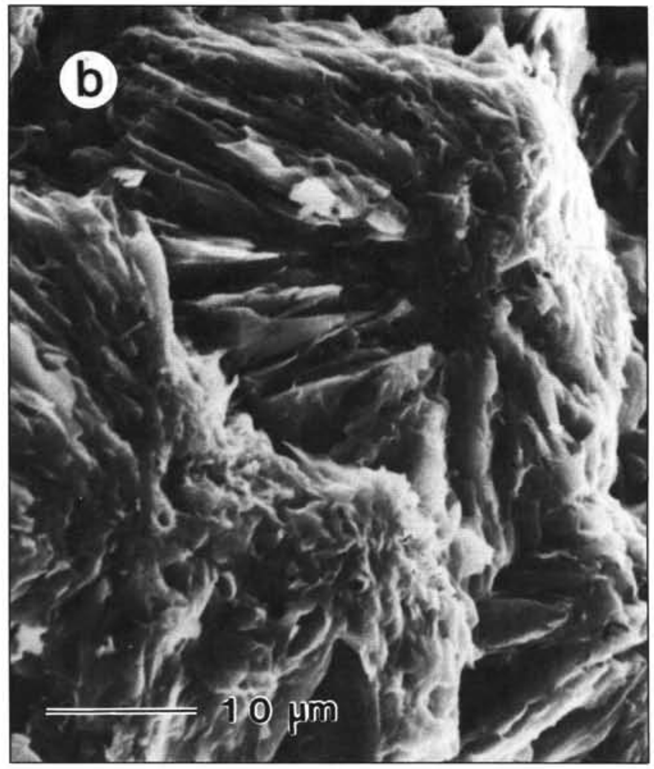
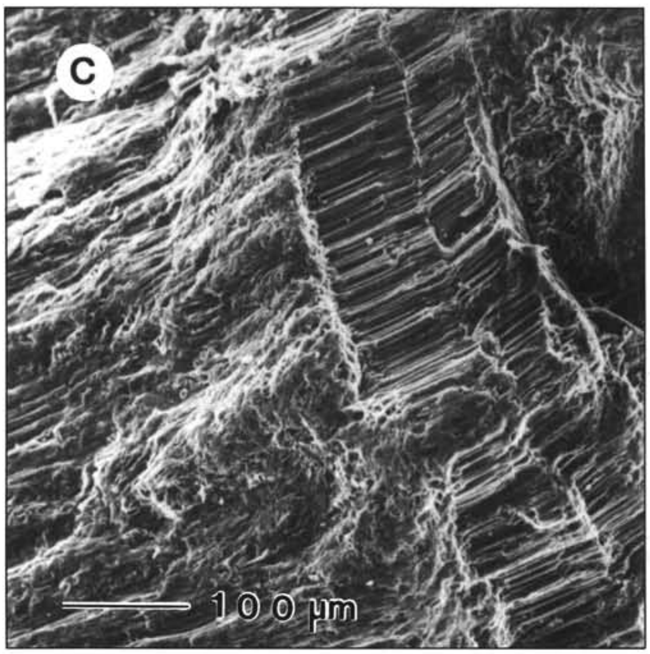


Figure 8. Scanning electron micrograph showing spherical clusters of rhombic siderite (S) crystals along with later euhedral laumontite (L) prismatic crystals and smectite (Sm) from about 796 m.

Sepiolite(?) — In a hornblende andesite lava flow at 1,762–1,780 m, a few soft, white, rounded chips of a clayey mineral that has a fibrous habit in SEM are present. The chips show a single XRD reflection at about 12.6 Å that remains unchanged following glycolation; however, no reflections are present after heating at 400°C for 1 h. These analyses suggest that the mineral is sepiolite (Starkey and others, 1984). Caramel-colored clay, also tentatively identified as sepiolite, occurs in cuttings from one geothermal drill hole in the Mount Hood area (Bargar and others, 1993). Hydrothermal sepiolite has been reported elsewhere in veins of mafic igneous rock, where it occurs as an alteration product of magnesium carbonates or silicates (Phillips and Griffen, 1981). Sepiolite formation by alteration of either of these two mineral groups would not appear compatible with conditions within either the Mount Hood or the SUNEDCO drill holes. Several of the Mount Hood drill holes contain abundant foreign materials, including drilling mud, added to facilitate drilling. Sepiolite is commonly used in drilling fluids for geothermal drill holes because







Left and above:

Figure 9. Scanning electron micrographs showing iron-rich platy smectite crystals that formed (a) in random orientation (~716 m), (b) as radiating clusters of crystals (~1,411 m), or (c) as fracture or vein fillings oriented perpendicular to the fracture surface (~1,411 m).

it does not flocculate at high temperatures (Greene and Goodman, 1982). Although the SUNEDCO cuttings studied were thoroughly washed, and foreign material was only occasionally observed, it seems likely that the sepiolite was introduced during drilling.

Celadonite — In field studies of hydrothermal alteration in the Breitenbush-Austin Hot Springs area, only one celadonite-bearing specimen was found in outcrops of late Tertiary rocks. However, chips of blue-green altered lithic tuff or clay were observed throughout much of the middle portion of the SUNEDCO hole at depths of 777–1,521 m. Celadonite, identified by XRD along with associated heulandite, smectite, laumontite, and mixed-layer chlorite-smectite, occurs at depths where present-day temperatures are 110°–130°C. In the lower part of the CTGH–1 drill hole, blue-green, clayey celadonite and tiny micaceous books of celadonite were found at measured temperatures of 65°–96°C (Bargar, 1988, 1990).

Smectite — Most samples above about 1,920 m contain variably colored (predominantly reddish and greenish) smectite that formed by precipitation from hydrothermal solutions in open spaces of fractures and cavities during alteration of glass or mafic minerals in lithic-crystal tuffs. Smectite shows a major XRD reflection at ~15 Å that shifts to ~17 Å following exposure to ethylene glycol vapors at 60°C for 1 h; heating to 550°C for 0.5 h results in collapse to ~10 Å. Many of these clays are poorly crystalline, which results in low, broad, asymmetrical XRD reflections. Associated hydrothermal minerals are pyrite, halloysite, chalcedony, kaolinite, heulandite, hematite, cristobalite, celadonite, laumontite, scolecite, calcite, and chlorite. The green color of many of the clays in this drill hole suggests that iron-rich nontronite probably is the prevalent smectite-group mineral; this is confirmed by semiquantitative EDS analyses indicating that Fe is the dominant cation present. The smectite commonly occurs as randomly oriented platy crystals (Figure 9a). However, it occasionally forms platy rosettes (Figure 9b) or vein fillings with plates oriented perpendicular to the vein margins (Figure 9c).

Mixed-layer chlorite-smectite — Mixed-layer chlorite-smectite was identified from the middle part of the SUNEDCO hole at 1,280–1,457 m. These medium- to dark-green clays have a strong (001) XRD reflection at ~14.5 Å and a weaker (002) peak at ~7.2 Å, which, following exposure to ethylene glycol vapors at 60°C for 1 h, show slight expansion to ~15.0 Å and ~7.3 Å, respectively. According to the identification guidelines for mixed-layer clay minerals (Hower, 1981), mixed-layer chlorite-smectite appears to be randomly interstratified and consists of ~80 percent chlorite. An

SEM study of one mixed-layer chlorite-smectite specimen from about 1,426 m shows random orientation of the platy crystals and the presence of Si, Al, Fe, Ca, Mg, Ti, and Mn in EDS. Several of the mixed-layer chlorite-smectite drill chips are shiny or striated and appear to have originated in fractures. The mineral sometimes is associated with later laumontite, heulandite, or stilbite/stellerite. Other associated hydrothermal minerals identified in the XRD analyses are calcite, quartz, and celadonite.

This mixed-layer chlorite-smectite in the SUNEDCO hole occurs where measured temperatures are 110°–130°C. Similar mixed-layer chlorite-smectite was found near the bottoms of several geothermal drill holes at Newberry volcano at temperatures of 110°–265°C (Keith and Bargar, 1988).

Chlorite — A few specimens from three zones in the drill hole, 1,417–1,472 m, 1,753–1,911 m, and 2,225–2,286 m (Figure 2), show broad, weak (001) XRD reflections at about 14.4 Å and slightly stronger (002) reflections at about 7.1 Å. For most specimens, the location of these reflections did not appear to change position significantly following glycolation, and the mineral is identified as chlorite. However, some slight apparent shifts in the (001) peaks noted for a few specimens suggest that a small smectite component is also present. The only other associated hydrothermal minerals identified by XRD analysis are laumontite, calcite, illite, and heulandite. Chlorite occurs over a wide range of temperatures in modern geothermal areas (Hulen and Nielson, 1986). In the SUNEDCO hole, the chlorite occurs at temperatures of 120°–140°C. In USGS Newberry 2 drill hole, the main chlorite zone occurs at temperatures between 120° and 265°C (Keith and Bargar, 1988).

Corrensite(?) — Five reddish lithic tuff samples from 1,800 to 1,950 m have a higher order reflection at about 25.3 Å and a subordinate reflection near 12.2 Å, which, after treatment with ethylene glycol vapors at 60°C for 1 h, shift to about 28.5 Å and 13.5 Å, respectively. Determination of the exact locations of these reflections is difficult because the peaks are mostly low, broad, and asymmetrical. Reflections for smectite and hematite are also present in some of the XRD analyses. For one of the samples containing smectite, heating to 400°C for 0.5 h resulted in destruction of all the reflections except for the ~10–Å smectite peak. Although these XRD data do not correspond to minerals with higher order reflections such as corrensite (a regular interstratification of chlorite and vermiculite), todusite, or rectorite (Starkey and others, 1984), somewhat similar XRD data, with glycolated reflections in the range of about 27 Å to 31 Å, were interpreted as an interstratification of corrensite and smectite by Inoue and others (1984). Tomita and others (1969) also report an interstratified mineral (chlorite-montmorillonite with another mixed-layer mineral?) having reflections at 26.8 Å and 12.6 Å that expand to 28.5 Å and 13.4 Å with ethylene glycol treatment; after heating at 500°C for 1 h only a 10-Å reflection remained. The mineral referred to in this report as corrensite(?) may be a complex interstratification of corrensite and smectite or possibly a mixture of other interstratified clay minerals.

Illite — Illite was identified by XRD analysis in samples from 1,426 m and in light-green clay chips and greenish clay-altered tuff fragments below 1,950 m. The majority of illite ~10.2-Å reflections are low, broad, asymmetrical peaks that shift to 10.0 Å following glycolation. Reflections slightly greater than 10 Å may indicate the presence of a very small amount of interlayered smectite, but no indication of smectite was observed on diffractograms of glycolated samples, and the mineral is referred to here as illite. Other hydrothermal minerals in the same XRD analyses are hematite, corrensite(?), chlorite, calcite, and a serpentine-kaolinite group mineral. Illite in the SUNEDCO hole occurs at temperatures of 120°–140°C. Hulen and Nielson (1986) indicate that illite in modern geothermal areas occurs at temperatures as low as about 120°C and as high as 330°C.

Serpentine-kaolinite group minerals — Scattered samples from the upper part of the drill hole, at depths of 274–747 m (Figure 2) contain clay-altered tuff fragments or chips of red, gray, or green clay that have XRD reflections for halloysite and kaolinite. Most of these specimens have low, broad, asymmetrical (001) reflections at ~7.2 Å, characteristic of halloysite (Brindley, 1980). However, a few specimens are less disordered and have (002) reflections near 3.57 Å in addition to the (001) reflections that are much sharper; the mineral probably is kaolinite. The XRD patterns show no change with glycolation, but the reflections are destroyed by heating to 550°C for 0.5 h. Other associated hydrothermal minerals identified on these X-ray diffractograms are smectite, hematite, analcime, and heulandite. Both kaolinite and halloysite were identified during studies of hydrothermal alteration near Mount Hood, where they probably formed by fumarolic alteration close to the summit of the mountain (Bargar and others, 1993). These kaolin minerals in the SUNEDCO hole are found at temperatures between about 40°C and 110°C, which according to Hulen and Nielson (1986) is the appropriate range for kaolinite.

Another serpentine-kaolinite group mineral identified in many samples near the bottom of the drill hole below 2,164 m (temperature ~140°C) is berthierine(?). Greenish metamorphosed tuff fragments in which this mineral occurs show fairly sharp (001) and (002) XRD reflections at about 7.1 Å and 3.54 Å, respectively, and semiqualitative chemical analysis by EDS on the SEM shows only Fe, Al, and Si. Other associated hydrothermal minerals identified in the same X-ray analyses are illite, siderite, calcite, and smectite. A mineral with similar characteristics was found in one specimen from a deserted mining area near Mount Hood (Bargar and others, 1993). An analogous serpentine-kaolinite group mineral referred to as septechlorite (no longer an accepted mineral name) was reported from USGS research drilling in the Mud Volcano area of Yellowstone National Park at temperatures of 110°–190°C (Bargar and Muffler, 1982).

Figure 10. Scanning electron micrograph of drusy subhedral quartz crystals that formed in a fracture or cavity filling at about 802 m.

Silica minerals

Cristobalite — A single specimen of red-orange silica from 802 m (temperature near 110°C) in the SUNEDCO hole has an XRD reflection at 4.07 Å, characteristic of cristobalite; reflections for smectite and heulandite are also present in the analysis. Cristobalite was identified in only two outcrop samples of late Tertiary volcanic rocks in the Breitenbush-Austin Hot Springs area, but it is fairly common in fractures and cavities of the Pliocene basaltic andesite lava flows in the lower part of CTGH–1 (Bargar, 1988, 1990). Sparse cristobalite occurs in late Tertiary volcanic rocks penetrated by geothermal drill holes near Mount Hood (Bargar and others, 1993), as well as in fractures and vugs in Pliocene and Pleistocene volcanic rocks from several geothermal drill holes at Newberry volcano (Keith and Bargar, 1988; Bargar and Keith, unpublished data). In all of these hydrothermal cristobalite occurrences, the measured temperatures were less than 150°C. Hydrothermal cristobalite commonly occurs as botryoidal masses (Bargar, 1990) and often forms as a disordered, poorly-crystalline phase during the transition from amorphous opal to microcrystalline chalcedony (Keith and others, 1978), with the botryoidal morphology being retained through the solid-state ordering process.

Chalcedony — Chalcedony is present in samples throughout much of the SUNEDCO hole (Figure 2). Microgranular or microfibrous, varicolored chalcedony occurs as lithic fragments in lithic-crystal tuffs, fills fractures and other cavities, and forms the matrix of silicified tuffs. Associated hydrothermal minerals identified by XRD or binocular microscope are pyrite, heulandite, chlorite, epidote, analcime, laumontite, calcite, smectite, and quartz. Some of the pyrite and all of the epidote are associated with chalcedonic lithic fragments and undoubtedly formed in an older hydrothermal system unrelated to the present geothermal system. The present measured temperatures (~90°–140°C) throughout the chalcedony section are within the lower range of temperatures for chalcedony in modern geothermal areas (Keith, 1988).

Quartz — Hydrothermal quartz was observed in several SUNEDCO samples (Figure 2). It usually occurs as one or more fragments of prismatic, colorless, euhedral crystals ~1 mm or less in length. Occasionally, quartz occurs as a druse of even smaller anhedral or subhedral crystals (Figure 10) that apparently formed on the walls of cavities or fractures. Some samples also contain irregularly shaped, colorless quartz fragments from larger broken crystals or massive vein fillings. Most of the quartzose fragments are monomineralic, but a few include quartz and earlier formed green smectite or pyrite. Quartz is also found in association with laumontite (Figure 4) and with mixed-layer chlorite-smectite.

Tiny, liquid-rich fluid inclusions, each with a very small vapor bubble, were observed in a few quartz fragments by use of refractive index oil. These fluid inclusions were not analyzed, but the tiny vapor bubbles suggest that the fluid-inclusion T_h values probably would be quite similar both to the measured temperatures and to the calcite T_h reported above. One frosted crystal fragment of quartz from 396 m contains liquid-rich secondary fluid inclusions (Figure 11) that homogenized at much higher temperatures than can be accounted for by the present-day measured temperatures of the hole (Figure 7) (Bargar, 1993). This crystal undoubtedly formed in a previous hydrothermal system of much higher temperature and was later incorporated within the tuff as a lithic fragment.

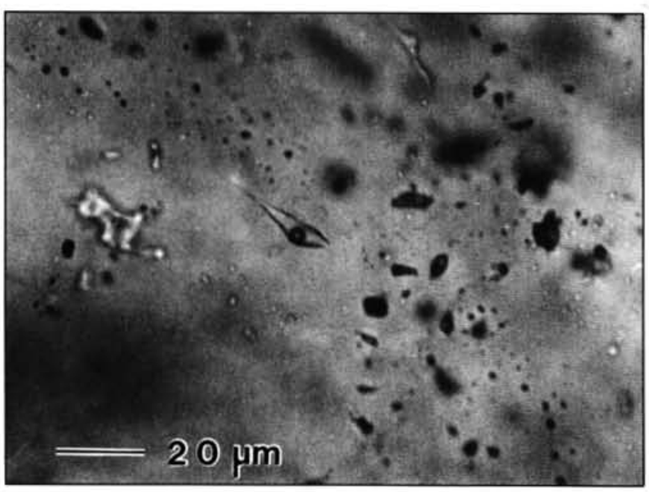


Figure 11. Photomicrograph of a liquid-rich secondary fluid inclusion in a hydrothermal quartz crystal lithic fragment from about 396 m.

Sulfide minerals

Chalcopyrite — A sample from 933 m contains a single chip of chalcopyrite with laumontite and heulandite. Chalcopyrite is a rare mineral in geothermal drill holes in the Cascade Range, but the copper-iron-sulfide mineral is found throughout the Western Cascades in occasional outcrops of old mining districts (Callaghan and Buddington, 1938). It also occurs in two geothermal drill holes near Mount Hood (Bargar and others, 1993).

Pyrite — Many samples throughout the SUNEDCO hole contain one to several pyrite-bearing chips. The pyrite most frequently occurs as individual tiny cubes or octahedra (Figure 12a) (usually <0.1 mm, but sometimes up to ~0.4 mm across) that fill fractures or are disseminated in the volcaniclastic grains. Massive or framboidal (Figure 12b) pyrite deposits are rare. In some tuffaceous drill chips, pyrite is found within lithic fragment components but not in the enclosing altered glassy matrix, suggesting that the pyrite formed in an older hydrothermal system. Cavity fillings of pyrite in association with hydrothermal minerals such as chalcedony, quartz, smectite, mixed-layer chlorite-smectite, heulandite, and laumontite may have been deposited from the present hydrothermal system.

Iron oxides

Hematite — Hematite is present throughout much of the SUNEDCO hole. Hematite was identified in many XRD analyses of red, clay-altered, lithic tuffs, although occasional analyses suggest that some of these tuffs contain amorphous iron oxide. Hematite or amorphous iron oxide also are present in a few fractures and rubbly flow margins. Closely associated hydrothermal minerals in the XRD samples are heulandite, laumontite, smectite, halloysite, chlorite, and mixed-layer chlorite-smectite.

Magnetite — Traces of possible hydrothermal magnetite were located in only three drill-cutting chips from this drill hole. Two of the chips consist of magnetite veins from a basaltic sill at 1,381 m. A third chip, from 719 m, contains magnetite with associated epidote. The latter occurrence probably is from a previous geothermal system.

Other minerals

Epidote — Epidote was identified on the basis of its distinctive yellow-green color and high refractive index (>1.70) and occurs in numerous samples from 600 to 1,800 m. Although epidote appears to occur throughout this depth range, no more than a single chip containing epidote was found at any one sample depth. Epidote most frequently occurs with chalcedony; in one specimen it is associated with magnetite, and in another with smectite and earlier hydrothermal quartz. Much of the epidote appears to reside in lithic rock fragments within lithic tuffs, which are the predominant rocks in the drill hole. Epidote is commonly found in the alteration halos of the small plutons in the Western Cascade Range of Oregon. The epidote-bearing clasts in the SUNEDCO hole may have been derived from such hydrothermal halos and incorporated into later formed lithic tuffs.

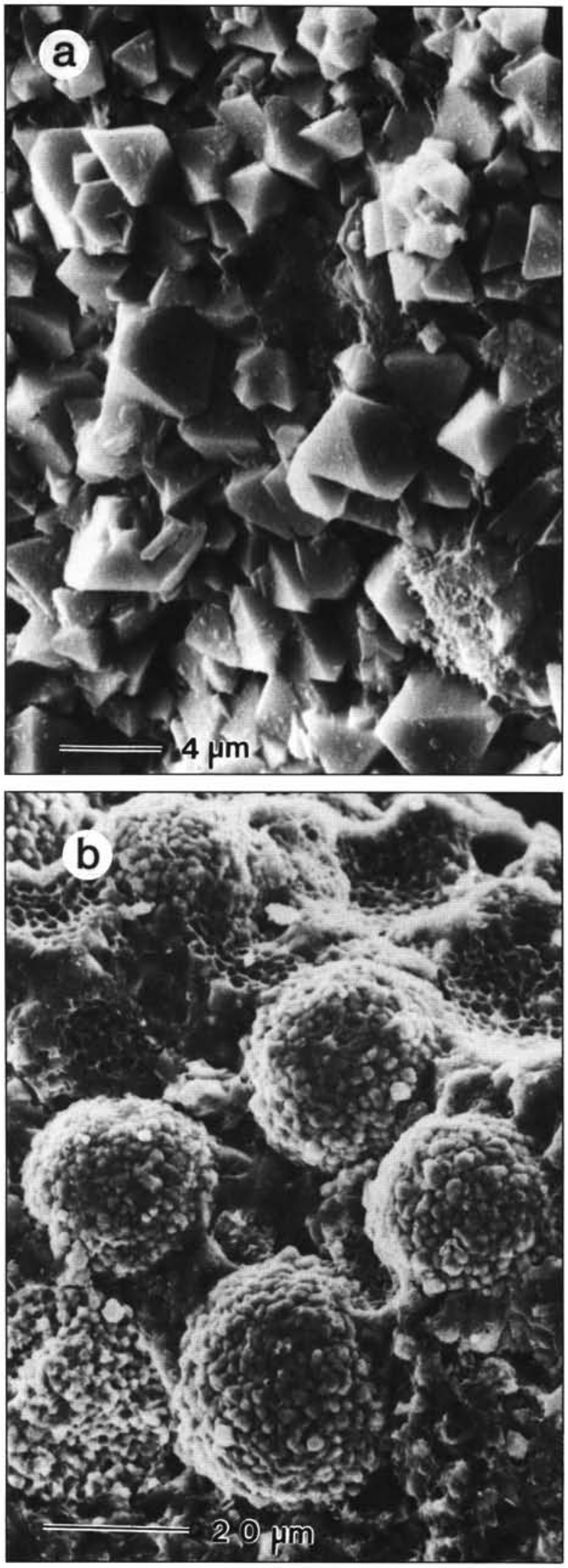


Figure 12. Scanning electron micrographs showing (a) octahedral pyrite crystals and later dusting of smectite from about 1,371 m, and (b) framboidal clusters of pyrite crystals and casts of the spherical crystal clusters of pyrite in later smectite from about 1,423 m.

Anhydrite — A few small, soft, tabular, colorless cleavage chips of anhydrite were identified from two narrow zones (1,792–1,817 m, and 1,908–1,920 m) in the lower part of the drill hole. Some of the unpolished anhydrite chips contain liquid-rich secondary(?) fluid inclusions with very small vapor bubbles (Figure 13). The T_h for 22 of these fluid inclusions in five sample chips (Table 2) range from 123° to 133°C, which is very close to the temperature-depth curve given in Blackwell and others (1986) (Figure 7). However, three primary(?) fluid inclusions from another sample chip have T_h of 152°C, 179°C, and 191°C, which indicates that this anhydrite crystal may have formed at significantly higher temperatures. Melting point temperatures for five of the anhydrite fluid inclusions are quite variable and are as high as +1.5°C. The fluid inclusions appear to be metastable (Roedder, 1984).

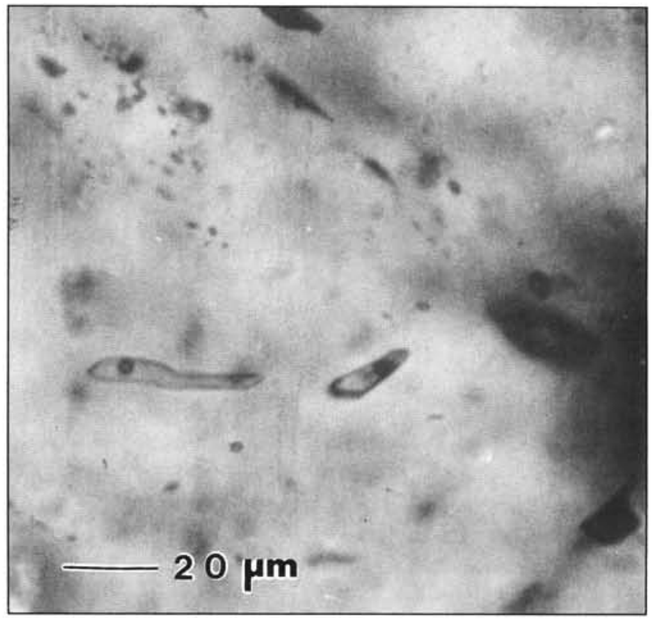


Figure 13. Photomicrograph of liquid-rich secondary fluid inclusions in an anhydrite cleavage chip from about 1,910 m.

Titanite(?) — A single grain from 1,759 m contains tiny wedge- or diamond-shaped crystals of titanite(?) (Figure 14) that consist of Ca, Ti, Si, and Al in EDS. Other hydrothermal minerals in the mixture of hornblende andesite and crystal-lithic tuff drill chips are laumontite, calcite, smectite and hematite. Authigenic titanite has been reported from New Zealand (Boles and Coombs, 1977) and the Cerro Prieto geothermal field of Mexico (Schiffman and others, 1985). Schiffman and others (1985) indicate that Al and Fe^{3+} substitute for Ti, and the titanite they described is very Al-rich. Aluminum- and iron-rich titanite was tentatively identified in drill cuttings from a geothermal drill hole near Mount Hood (Bargar and others, 1993). Schiffman and others (1985) indicated that the Cerro Prieto titanite probably formed at temperatures below 150°C, which is similar to the conditions for the occurrence of titanite(?) in the SUNEDCO hole.

Garnet(?) — Two drill chips from a lithic tuff unit at 1,369 m contain anhedral to subhedral crystals of a yellow-orange mineral containing Ca, Fe, ± Al, and Si in EDS. Crystal morphology (Figure 15) and the semiquantitative chemistry suggest that the mineral might be andradite garnet. Associated hydrothermal minerals in these chips are calcite, pyrite, and laumontite; celadonite and mixed-layer chlorite-smectite were also identified from this sample depth. Garnets are reported from several active geothermal systems where temperatures exceed 300°C (Bird and others, 1984). If the mineral is garnet, it most likely formed in an older, higher temperature hydrothermal system and was later incorporated into the lithic tuff unit.

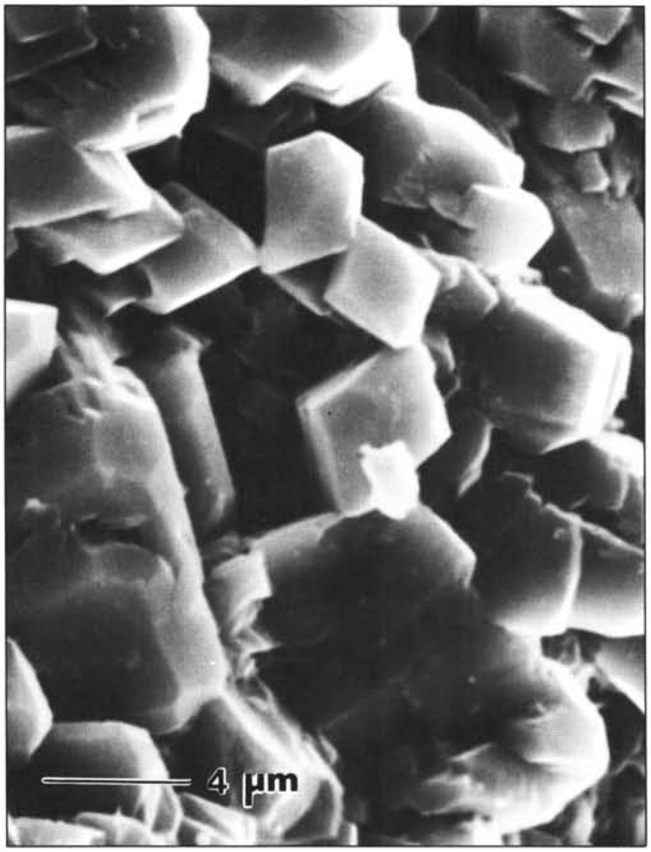


Figure 14. Scanning electron micrograph of subhedral titanite(?) crystals from about 1,759 m. Some of the titanite(?) crystals appear to be wedge shaped.

DISCUSSION

The 2,457-m-deep SUNEDCO 58–28 drill hole penetrated late Tertiary volcanic and volcaniclastic rocks, as well as a few minor intrusions. Drill cuttings from this geothermal exploration hole are altered to zeolites (analcime, epistilbite, heulandite, laumontite, mordenite, scolecite, and stilbite/stellerite), carbonates (calcite and siderite), clays (smectite, celadonite, mixed-layer chlorite-smectite, chlorite, serpentine-kaolinite group minerals, corrensite[?], and sepiolite[?]), silica minerals (cristobalite, chalcedony, and quartz), pyrite, iron oxide, and trace amounts of a few other hydrothermal minerals including epidote, chalcopyrite, anhydrite, magnetite, garnet(?), and titanite(?). Glassy material in the tuffs is altered to zeolites and clays; these minerals along with other hydrothermal minerals also appear to have formed in fractures and cavities throughout most of the drill hole. Hematite and amorphous iron oxide occur as open space deposits and alteration of mafic minerals.

A nonequilibrium temperature of ~141°C (A.F. Waibel, unpublished data, 1982) was measured at the bottom of the drill hole, although the actual bottom-hole temperature may have been near 150°C (Blackwell and Baker, 1988). Homogenization temperatures (T_h)for secondary liquid-rich fluid inclusions in calcite, and anhydrite suggest that these fluid inclusions may have formed in the present-day geothermal system, because the minimum T_h values are nearly coincident with the measured temperatures at the fluid-inclusion sample depths (Taguchi and others, 1984). The fluid inclusions in calcite and anhydrite have mostly (only a single exception) maximum T_h values of less than the 174°C geothermometer temperature that Ingebritsen and others (1989) reported for the aquifer supplying the nearby Breitenbush Hot Springs dilute Na-Cl waters (Mariner and others, 1993). The T_h measurements for fluid inclusions in primary quartz crystals from near the bottom of the drill hole range from near the estimated temperature at the sample depth to as much as 42°C higher than the geothermometer temperature for the Breitenbush Hot Springs water. This suggests that these fluid inclusions trapped water from a different aquifer than the one feeding the thermal springs. Also, limited T_m measurements for the near-bottom fluid inclusions indicate that the trapped water is from an aquifer that has a significantly greater salinity than Breitenbush Hot Springs.

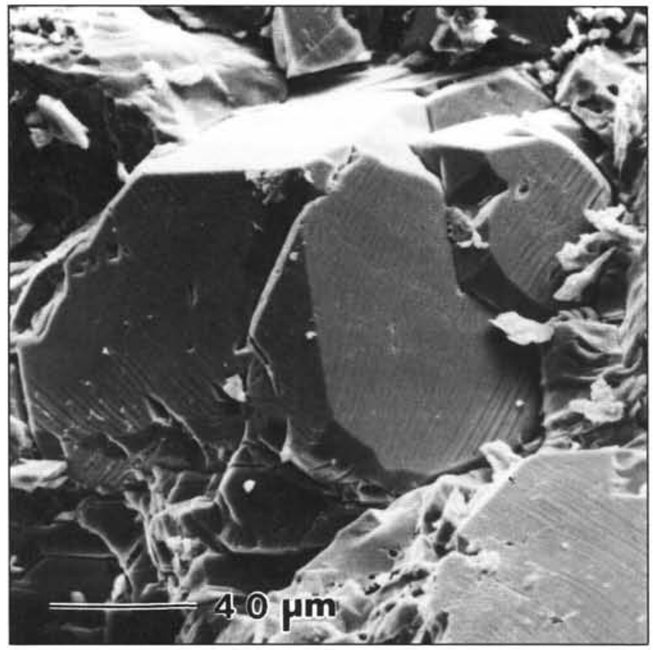


Figure 15. Scanning electron micrograph of subhedral garnet(?) crystals from about 1,369 m.

Except for some mineral paragenesis observations in SEM, the sequence of mineral formation is difficult to determine from the drill-cutting samples. Although trace amounts of epidote are widespread in the cuttings, which might suggest temperatures of at least 230°C (Seki, 1972), petrographic observations indicate that the epidote, along with several other hydrothermal minerals including garnet(?), some pyrite, quartz, and chalcedony, is confined to lithic fragments in tuffs and tuffaceous sedimentary deposits and was incorporated by fragmentation of older geothermal halos. It has previously been pointed out that some of the hydrothermal alteration minerals (especially epidote) in the SUNEDCO 58–28 chips formed at higher temperatures than were measured in this drill hole (Keith, 1988). Other misleading pieces of evidence for higher temperatures in this drill hole are (1) the presence of garnet(?), which forms at temperatures above 300°C (Bird and others, 1984), and (2) fluid inclusion T_h values of 232°–274°C for a quartz fragment from the shallower part (396 m) of the drill hole.

CONCLUSIONS

Hydrothermal-mineralogy and fluid-inclusion studies of the SUNEDCO 58–28 drill hole samples indicate that most of the alteration minerals probably formed in the present-day geothermal system. The majority of hydrothermal minerals precipitated from Na-Cl water similar to that of nearby Breitenbush Hot Springs. However, some hydrothermal chalcedony, quartz, pyrite, and, especially, epidote and garnet(?) formed from one or more older, higher temperature geothermal systems. These minerals occur in lithic rock fragments that were either eroded or broken up by explosive volcanic activity and later were incorporated into the tuffaceous units penetrated in the SUNEDCO drill hole. A change in clay mineralogy from smectite/celadonite to illite/serpentine-kaolinite along with slightly higher fluid-inclusion T_h values and lower T_m values at about 2,000 m suggest that a second, more saline aquifer may be present near the bottom of the drill hole.

ACKNOWLEDGMENTS

This study was aided by electron microprobe analyses provided by P. Weston and scanning electron micrographs supplied by R.O. Oscarson. Special thanks go to A.F. Waibel, Columbia Geoscience, Hillsboro, Oregon, for making the SUNEDCO 58–28 drill hole samples available for this study. Reviews by R.A. Bailey and M.H. Beeson improved the manuscript and are gratefully acknowledged.

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Geothermal exploration in Oregon, 1992–1993

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INTRODUCTION

After several years of declining activity, geothermal activity in Oregon increased in the past two years. There was no change in the low level of leasing, but drilling picked up substantially in two areas: Pueblo Valley and Vale.

LEASING

There were no geothermal lease sales during 1992 or 1993. Table 1 shows leasing trends for these years. In 1992, all new acreage was in the Newberry volcano area, Deschutes County. In 1993, leased acreage was in the Newberry area, elsewhere in Deschutes County, and in the Vale area, Malheur County.

DIRECT-USE PROJECTS

The Geo-Heat Center at the Oregon Institute of Technology (OIT), Klamath Falls, received in 1992 a contract from the U.S. Department of Energy to study increasing the use of geothermal energy. The study is concentrating on furthering the use of low- and moderate-temperature hydrothermal resources and of geothermal heat pumps. The objective of the Geo-Heat Center is to provide technical assistance to anyone who is interested or involved in the development of geothermal energy for direct-use applications.

The Geo-Heat Center has studied the effect of the fall 1993 earthquakes in the Klamath Falls area on the local geothermal resource (Lienau and Lund, 1993). Approximately 500 wells tap geothermal fluids from 50° to 110°C (122° to 230°F) at depths from 30 to 600 m (100–1,970 ft). Water levels in hot-water wells have increased since the earthquakes. At the same time, water levels in

Table 1. *Geothermal leases in Oregon, cumulative, 1992, and 1993*

Types of leases	Numbers	Acres
Cumulative–Leases issued since 1974:		
Noncompetitive, USFS	385	718,867
Noncompetitive, USBLM	274	415,778
KGRA, USFS	18	18,388
KGRA, USBLM	66	125,740
Cumulative–Leases relinquished since 1974:		
Noncompetitive, USGS	265	561,112
Noncompetitive, USBLM	264	405,215
KGRA, USFS	7	11,825
KGRA, USBLM	55	101,243
Federal leases issued during 1992, USFS	7	7,197
Federal leases issued during 1992, USBLM	5	8,072
Federal leases closed 1992, USFS and BLM	9	9,464
Federal leases issued during 1993, USFS	2	3,094
Federal leases issued during 1993, USBLM	7	8,981
Federal leases closed 1993, USFS and BLM	12	29,582
Federal leases in effect, 12/31/93:		
Noncompetitive, USFS	120	157,755
Noncompetitive, USBLM	10	10,563
KGRA, USFS	11	6,563
KGRA, USBLM	11	23,897
Federal income from geothermal leases, 1992		$153,634
Federal income from geothermal leases, 1993		$110,637

Figure 1. Anadarko Petroleum flow-test well 66-22A, located near Fields in southern Harney County.

five monitored cold-water wells decreased dramatically. Changes have been from 0.9 to 2 m (3–7 ft). The Klamath Medical Clinic well started an artesian flow of 115 L/min (30 gal/min) before the earthquakes and increased to 570 L/min (150 gal/min) afterwards with no change in temperature. Some wells did change in temperature, and one well developed a hydrogen sulfide odor.

In 1992, the Klamath Falls heating district discovered it would need additional buildings hooked up to the system to remain economically viable. The 82°C (180°F) water was used by a total of 14 public buildings in the downtown district. The Geo-Heat Center at OIT developed a marketing strategy to address rates, customer retrofit costs, financing, system reliability, and other factors. Since that time, eleven additional buildings have been or are about to be served by hot-water heat. Early last year, the city of Klamath Falls encouraged property owners to more quickly take advantage of the state's business energy tax credit to encourage investment in energy-saving technology, recycling, and conversion to renewable energy sources like geothermal for space heating. Through tax credits, the state will reimburse property owners 35 percent of investment for these purposes over five years, giving downtown businesses an incentive to use geothermal energy.

Liskey Farms Greenhouses, just south of Klamath Falls, has expanded from about 0.7 acres to approximately 1.5 acres. Tomatoes and jalapeno peppers are grown. Near Craine Prairie, east of Burns, Geo-Culture, Inc., is planning a 21.5-acre greenhouse operation to grow tomatoes. A test well has been drilled for installation of a downhole heat exchanger.

OREGON DEPARTMENT OF ENERGY (ODOE)

ODOE was active in several programs dealing with geothermal energy. The agency is contractor for the Geothermal Education Office, a nonprofit organization working to educate today's youth about geothermal energy and its place in the energy picture. Targeting grades four through nine, a self-contained educational unit is being designed to teach the following aspects of geothermal energy: geologic origin, how it is used, environmental impacts, and place in Pacific Northwest energy use.

ODOE continues to compile all available information and documentation on operations at geothermal power plants in the United States. Data for 64 power plants are collected and stored electronically. Field visits and interviews were conducted over the past two years at new geothermal plants at Brady and Steamboat in Nevada. The updated database is submitted to the Bonneville Power Administration (BPA) annually.

The agency regularly communicates with Northwest environmental organizations to support advocacy of technologies for renewable energy such as geothermal. It is also an ex-officio member of the Central Oregon Citizens Working Group, advising on Newberry volcano development issues.

ODOE performed a feasibility study to determine under what circumstances a ground-coupled heat pump program could meet BPA cost-effectiveness standards and other billing-credit criteria. Such a program was found not to be feasible, in spite of some utility support. Impediments, such as the high system capital cost, were identified and included in the findings.

OREGON WATER RESOURCES DEPARTMENT (WRD)

WRD has been working with the City of Klamath Falls and the Department of Environmental Quality to streamline the process for obtaining the necessary permits for reinjection wells. Users of the resource in Klamath Falls have, for the most part, switched to injection of spent geothermal effluent.

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES (DOGAMI)

Agencies of 10 western states are compiling geothermal databases for wells and springs. DOGAMI is funded through a subcontract from the OIT Geo-Heat Center for its part of the project entitled "State Geothermal Energy Research, Development, and Database Compilation." Prime funding is from the U.S. Department of Energy, Geothermal Division. This project is phase 1 of the low-temperature geothermal resources and technology transfer program. The purposes of the project are to (1) update the inventory of the nation's low- and moderate-temperature geothermal resources, (2) study the location of the resources relative to potential users, and (3) collect and disseminate information necessary to expand the use of geothermal heat pumps. DOGAMI's involvement is primarily the first task listed; the agency shares responsibility with OIT for the second task.

DOGAMI has published an open-file report on the power-generation potential of Newberry volcano and on deep thermal data from the Cascades (Black, 1994; Blackwell, 1994). The "rain curtain" effect is also discussed in the report.

REGULATORY ACTIONS AND INDUSTRY DRILLING ACTIVITIES

Table 2 shows active state geothermal permits during 1992 and 1993, including wells permitted and drilling activity that occurred. In 1992, drilling activity included the deepening of a well by California Energy Company in the Bend Highlands area of Deschutes County (Permit 147D). The well has since been plugged and abandoned. In 1993, drilling included the deepening of a 1989 well

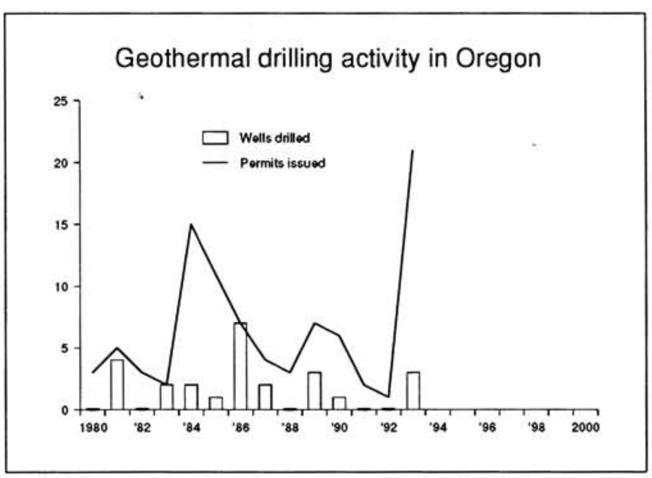

Figure 2. Geothermal well permits and drilling since 1980. Geothermal wells are deeper than 2,000 ft.

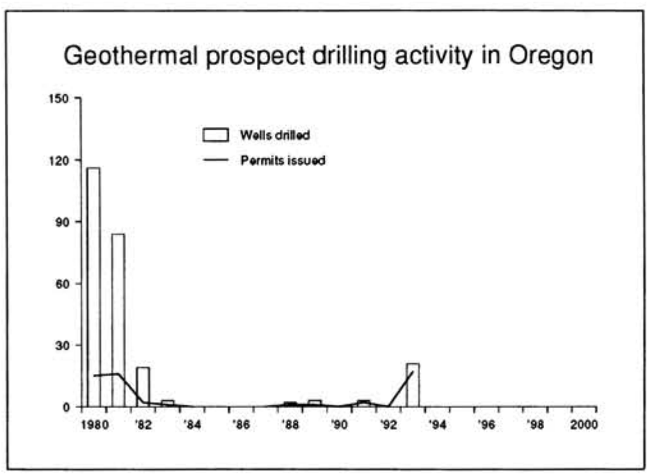

Figure 3. Geothermal prospect-well permits and drilling since 1980. Prospect wells are 2,000 ft or less in depth. One prospect permit may include several wells

and the drilling of two additional geothermal wells by Anadarko Petroleum Corporation in the Pueblo Valley of Harney County, in sec. 22, T. 27 S., R. 33 E. A press release by the company in November 1993 indicated that one of the wells reached a total depth of 724 m (2,376 ft) and was flow-tested at an average rate of 1,100 L/min (290 gal/min) with a wellhead temperature of 147°C (296°F). Temperatures in the wellbore exceeded 150°C (300°F). This well and the offset wells were completed for long-term observation of reservoir temperatures and pressures during possible development of the field for electric power generation. Anadarko holds 8,120 net lease acres at the Pueblo Valley discovery site.

Concurrently with drilling and testing, Anadarko monitored nearby Borax Lake water quality and quantity conditions, as required in the federal environmental assessment. Monitoring included air temperature, shallow water temperature, deep vent temperatures, water depth using a pressure transducer, and water temperature at a hot spring north of the lake.

In addition to the activity reflected in Table 2, DOGAMI and the

Table 2. *Geothermal permits and drilling activity in Oregon, 1992–1993*

Permit no.	Operator, well, API number	Location	Status, proposed or actual total depth
118	Geo Operator N-1 36-017-90013	SW¼ sec. 25 T. 22 S., R. 12 E. Deschutes County	Abandoned; 10-27-92.
125	Geo Operator N-2 36-017-90018	NE¼ sec. 29 T. 15 S., R. 12 E. Deschutes County	Abandoned; 11-02-92.
126	GEO Operator N-3 36-017-90019	NW¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Abandoned; 10-25-92.
131	GEO Operator N-4 36-017-90023	NE¼ sec. 35 T. 21 S., R. 13 E. Deschutes County	Abandoned; 10-28-92.
132	GEO Operator N-5 36-017-90024	NE¼ sec. 8 T. 22 S., R. 12 E. Deschutes County	Abandoned; 10-30-92.
147D	Calif. Energy Co. CE-BH-7 36-017-90032	NE¼ sec. 20 T. 17 S., R. 10 E. Deschutes County	Application to deepen; PTD 1,677 m (5,500 ft).
150	Anadarko Petroleum Pueblo Valley 52-22A 36-025-90007	NW¼ sec. 22 T. 37 S., R. 33 E. Harney County	Canceled; 8/13/93.
151	Anadarko Petroleum Pueblo Valley 66-22A 36-025-90008	SE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Canceled; 8/13/93.
152	Vulcan Power Co. VP-83-29 36-017-90034	NE¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Application; PTD 3,050 m (10,000 ft).
153D	Anadarko Petroleum Pueblo Valley 25-22A 36-025-90009	NW¼ sec. 22 T. 37 S., R. 33 E. Harney County	Deepening; TD not released.
154	Anadarko Petroleum Pueblo Valley 52-22A 36-025-90010	NE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Drilled and suspended; TD not released.
155	Anadarko Petroleum Pueblo Valley 66-22A 36-025-90011	SE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Drilled and suspended; TD 724 m (2,376 ft).

Table 2. *Geothermal permits and drilling activity in Oregon, 1992–1993 (continued)*

Permit no.	Operator, well, API number	Location	Status, proposed or actual total depth
156	Trans Pacific Geothermal ESI-A-L Alt 36-045-90007	NE¼ sec. 33 T. 37 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
157	Trans Pacific Geothermal ESI-A-S Alt 36-045-90008	NE¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Drilled and suspended; TD 1,755 m (5,757 ft).
158	Trans Pacific Geothermal ESI-B-L 36-045-90009	SE¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
159	Trans Pacific Geothermal ESI-B-S 36-045-90010	SE¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
160	Trans Pacific Geothermal ESI-C-L 36-045-90011	NE¼ sec. 34 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
161	Trans Pacific Geothermal ESI-C-S 36-045-90012	NE¼ sec. 34 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
162	Trans Pacific Geothermal ESI-D-L 36-045-90013	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
163	Trans Pacific Geothermal ESI-D-S 36-045-90014	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
164	Trans Pacific Geothermal ESI-D-L Alt 36-045-90015	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
165	Trans Pacific Geothermal ESI-D-S Alt 36-045-90016	NW¼ sec. 33 T. 18 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
166	Trans Pacific Geothermal ESI-E-L 36-045-90017	NE¼ sec. 4 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
167	Trans Pacific Geothermal ESI-E-S 36-045-90018	NE¼ sec. 4 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
168	Trans Pacific Geothermal ESI-F-L 36-045-90019	SE¼ sec. 3 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
169	Trans Pacific Geothermal ESI-F-S 36-045-90020	SE¼ sec. 3 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
170	Trans Pacific Geothermal ESI-G-L 36-045-90021	NW¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
171	Trans Pacific Geothermal ESI-G-S 36-045-90022	NW¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).
172	Trans Pacific Geothermal ESI-H-L 36-045-90023	NE¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 2,134 m (7,000 ft).
173	Trans Pacific Geothermal ESI-H-S 36-045-90024	NE¼ sec. 11 T. 19 S., R. 45 E. Malheur County	Permitted; PTD 1,524 m (5,000 ft).

U.S. Bureau of Land Management (BLM) issued permits to Trans-Pacific Geothermal Corporation for 21 temperature gradient wells in the Vale area in Tps. 18–19 S., R. 45 E., and 17 were drilled for temperature data to fine-tune the location for drilling a deep geothermal well. The deep test well, ESI-A-S Alt (Permit 157), was drilled in February 1994 and is suspended at this time. Figures 2 and 3 show the geothermal permitting and drilling statistics since 1980.

During 1992, DOGAMI and BLM abandoned five temperature gradient wells around Newberry volcano, using bonds posted by the operator, Geo-Operator. The company had left the wells deserted, and the DOGAMI Governing Board had declared the wells to be unlawfully abandoned.

U.S. GEOLOGICAL SURVEY (USGS)

Keith Bargar has been conducting studies of hydrothermal alteration of drill cores from Newberry volcano. The cores are from the USGS N-2 hole in the caldera as well as some industry wells on the flanks of the volcano. The results of the study will be presented in a USGS Bulletin, probably in 1995. Bargar conducted similar studies on drill-hole cuttings from the geothermal exploration well SUNEDCO 58-28 near the High Cascade-Western Cascade boundary at Breitenbush Hot Springs in Marion County. These are discussed in his report beginning on p. 75 of this issue.

Charlie Bacon is preparing a 1:24,000 geologic map of the Mazama caldera (Crater Lake area) on the basis of his field mapping over the past years. The map will include photographic panoramas as colored geologic sections. (See also Bacon, 1992; Bacon and others, 1992.)

USDA FOREST SERVICE (USFS)

In 1993, USFS released two draft environmental impact statements (DEIS) for the Newberry volcano area, the *Newberry National Volcanic Monument Comprehensive Management Plan* (12/93) and the *Newberry Geothermal Pilot Project* (1/94). Both have undergone comment periods and are being prepared in final form. Major concerns expressed in public comments have been air emissions, impacts to ground water and hot springs, staged vs. cumulative development, effect on the Monument, and decommissioning.

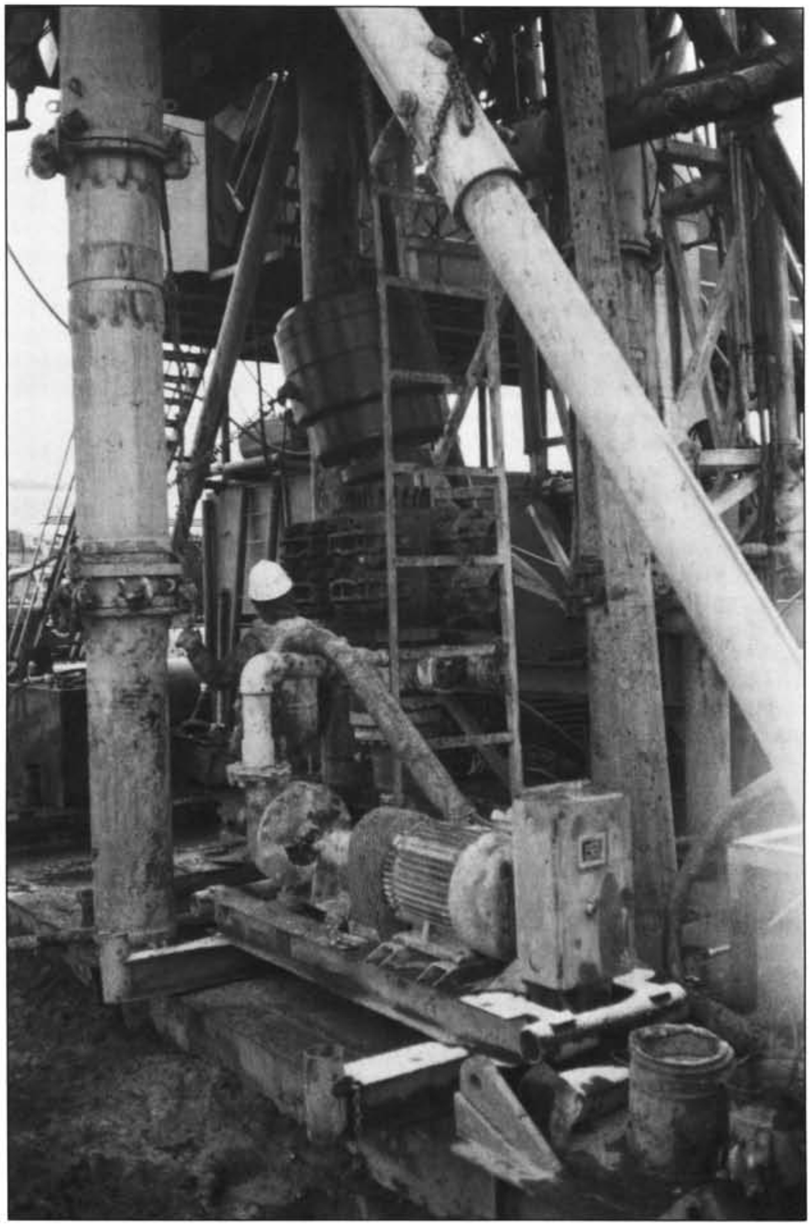

Figure 4. Installing blowout preventers on the Trans-Pacific Geothermal well ESI-A-S Alt near Vale, Malheur County, during February 1994.

The latter DEIS is in response to a proposal by CE Exploration Company of Portland to build and operate a geothermal pilot project and supporting facilities capable of generating 33 megawatts (MW) of electric power in the Deschutes National Forest. The facilities would include a power plant, access roads, exploration and production wells, a power transmission line, and a switchyard. The project would be located on the west flank of Newberry volcano on federal geothermal leases. In the DEIS, the USFS alternative identified 20 well-pad locations, 14 of which could be used, and three power plant locations. A single-pole transmission line design and a route away from the Forest Service road were proposed.

U.S. BUREAU OF LAND MANAGEMENT (BLM)

The above-mentioned drilling activity at Pueblo Valley was performed under an environmental assessment (EA) written by BLM in 1990. The EA had been appealed to the Interior Board of Land Appeals (IBLA) by seven interest groups, due to the proximity to Borax Lake and the Borax Lake chub. These interest groups felt that the proposed project warranted an environmental impact statement (EIS). In May 1993, the IBLA upheld the BLM decision, which consisted of a "finding of no significant impact," and stated that an EIS would not be needed until further geothermal development is contemplated.

BLM conducted its own baseline environmental data monitoring of Borax Lake before, during, and after the drilling of the Anadarko wells in 1993. The USGS assisted in the design of this monitoring. This work satisfied requirements of the environmental assessment and included a monitoring station at the lake to measure air temperatures and deep vent temperatures hourly. Additional measurements included shallow water temperatures and water depths, for which a pressure transducer was used. Recorded data were electronically available at BLM offices. Visual assessment of the lake and springs to the north was also conducted. Values measured at the monitoring station, including air temperature, shallow water temperature, deep vent temperature, and water depth, were recorded and, periodically, water temperatures at the hot springs. Samples were taken of the effluent of the lake during flow tests for general water chemistry determination. Analyses included carbonate, bicarbonate, hydroxide, total alkalinity, cation/anion balance, bromide, chloride, conductivity, fluoride, nitrate, pH, silica, sulfate, total dissolved solids, and turbidity. Trace element analysis was also conducted, including 15 elements.

BLM also conducted several additional studies in and around Borax Lake. These included census of the Borax Lake chub, alga and invertebrate studies in the lake, update of the 1987 chub recovery plan and the 1987 chub habitat management plan. In addition, the agency has contracted with the USGS and the U.S. Bureau of Mines to do a mineral assessment of parts of southeast Oregon in the Burns and Malheur districts.

In September 1993, BLM administratively enlarged the boundaries of the Newberry Known Geothermal Resources Area (KGRA) by 13,345 acres. Added acreage includes secs. 7, 8, and 9, T. 21 S., R. 13 E.; sec. 18, T. 22 S., R. 13 E.; secs. 9, 10, 12, 16, 17, 20, 30, 31, and 32, T. 21 S., R. 12 E.; and secs. 5, 6, 8, 13, 14, 15, and 16, T. 22 S., R. 12 E.

BLM is currently undertaking a mineral assessment of parts of the Burns and Malheur districts with the help of the Bureau of Mines and the USGS. No plans for publication of the results have been announced.

BONNEVILLE POWER ADMINISTRATION (BPA)

The main goal of BPA's geothermal program is to initiate geothermal development in the Pacific Northwest, to make sure it will be available to meet the region's energy needs. The program has focused on developing pilot power projects at sites with potential to support at least 100 MW of capacity. As an incentive to developers, BPA offered to buy the output from up to three projects. Two of the projects are in Oregon: the 30-MW project of CE Exploration Co. (CEE) at Newberry volcano and a 30-MW project by Trans-Pacific Geothermal Corp. at Vale. The Eugene Water and Electric Board (EWEB) is a partner in the Newberry project, and the Springfield Utility Board is a partner at Vale. Trans-Pacific's Vale leasehold is in the Vale Known Geothermal Resource Area, which extends from 1 to 5 mi southeast of Vale, near the Idaho border. A "plan of exploration" to drill and test up to 10 wells was approved by BLM at the latter project in October 1993. An exploration well was drilled in February 1994 (details elsewhere in this report). For the Newberry project, CEE and EWEB undertook an innovative public involvement program aimed at informing community leaders in the Bend-Sunriver-LaPine area about the project. The Central Oregon Geothermal Working Group (COGWG) represented a wide range of interests, from the Sierra Club to the Lodgepole Dodgers, a snowmobile club. The group met monthly. Each meeting centered around a topic or issue, such as environmental baselines or air emissions, usually featuring an outside speaker.The group also traveled to California's large geothermal producer, The Geysers, to view an operating field.

The pilot projects were supported by over 30 other activities aimed at increasing public knowledge and acceptance of geothermal technology. These activities included environmental studies, economic impact studies, public education projects, videos, technology development, outreach to environmental groups, and geothermal heat pump projects.

RELATED ACTIVITIES

The Newberry National Volcanic Monument Advisory Council has been meeting bimonthly to track the USFS process. The discussion is primarily driven by issues concerning threatened and endangered species and vegetation management. In its public-involvement program, CE Exploration has continued to hold informational meetings of its working group to educate key individuals and groups on what to expect of geothermal development.

The Nature Conservancy, an organization that buys land for conservation purposes, purchased 320 acres of property including Borax Lake and several hot springs to the north of the lake. The sale price was $320,000, and the sale was final in October 1993. The group has taken chub counts every fall since 1986.

Michael Cummings and Anna St. John, both of Portland State University, prepared a report for the Bonneville Power Administration on the hydrogeochemical characterization of the Borax Lake area. The report discussed the geologic and topographic evolution of the Alvord Desert, development of a sinter cap at the lake, lithology types at various hot-spring reservoirs based on strontium and radium isotopes, and the geochemistry of Alvord, Mickey, and Borax Hot Springs. It calculated reservoir temperatures for the three hot springs based on measurements by chemical and isotope geothermometers, the nature of the geothermal system, and water source and residence times.

ACKNOWLEDGMENTS

Numerous individuals and organizations have contributed to this report. Jackie Clark of BLM provided the federal leasing data. George Darr of BPA, Alex Sifford of ODOE, Gene Culver of OIT, and Jerry Black and George Priest of DOGAMI provided information on their agencies' activities. For other contributions we thank Keith Barger and Charlie Bacon of the USGS and Michael Zwart of the Oregon Water Resources Department.

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MLR recognizes outstanding reclamation

The Mined Land Reclamation Program (MLR) of the Oregon Department of Geology and Mineral Industries presented reclamation awards to six mine operators during the Oregon Concrete and Aggregate Producers Association annual convention in Sunriver, Oregon, on Saturday, May 21, 1994. The awards and the winners are listed and described below.

- Outstanding Operator Award:
  A tie between Karban Corporation, Washington County, and Eagle-Picher Minerals, Inc., Harney County
- Small Operator Award:
  O & S Quarry Products, Tillamook County
- Outstanding Reclamation Award:
  Bonnanza Mining, Inc., Baker County
- Exploration Award:
  Cambiex, Josephine County
- Good Neighbor Award:
  Clackamas Sand and Gravel, Clackamas County

Outstanding Operator Award (two winners): The outstanding operator award is given for excellence in mine development and operation on a daily basis, such as paying exceptional attention to detail, maintaining on-site controls to prevent or minimize degradation of water quality, going beyond reclamation requirements of Oregon laws and administrative rules, using innovative techniques that improve the quality of operation and enhance environmental protection, and operating in a manner that reduces reclamation liability by completing concurrent reclamation on sand and gravel or industrial mineral sites.

Joint winners of the Outstanding Operator Award for this year are Karban Corporation, for its aggregate operation near Timber in Washington County, and Eagle-Picher Minerals, Inc., for its diatomaceous earth mining complex located about 40 miles west of Burns in Harney County.

Karban received its award because of its proactive approach to solving problems. Karban developed a major regional quarry along Pennoyer Creek, which drains into Salmonberry River, considered by some fisheries biologists to be one of the most pristine and productive watersheds in Oregon. During the rainy winter season, Karban went to great efforts to stabilize a large stockpile, trap fine sediment above storm water ponds, and improve the water quality of the storm-water discharge. The operators monitored their own activities and did not wait for regulatory agencies to tell them they had a problem that needed attention. Consequently they were able to prevent problems before they developed.

Eagle-Picher received its award because the operators have been extremely successful in conducting concurrent reclamation at the Breede Desert site. Soil and overburden are stripped and hauled to an area undergoing reclamation, thereby reducing the amount of stockpiled material, keeping disturbed acreage to a minimum, increasing species diversity by keeping any seed in the soil viable, and reducing handling costs. The operator has established vegetation test plots to determine which seed mix works best in the relatively harsh environment and is attempting to establish squaw apples in order to develop deer browse.

Small Operator Award: This award is given for the same criteria as for the Outstanding Operator Award (listed above), except on a smaller scale.

Winner of this award is O & S Quarry Products, a family-owned quarry located on a 175-acre family farm in Tillamook County. Although the quarry was near the highway, it was hidden from view by a topographic barrier. After quarrying was completed, the owners backfilled the quarry wall into a slope and created a shallow wetland by hand-transplanting vegetation and introducing frogs from nearby ponds into the pond that filled the depression left in the pit floor. This outstanding reclamation was particularly noteworthy because it was done with limited resources.

Outstanding Reclamation Award: This award is given to an operator who goes beyond minimum requirements for reclamation or who uses an innovative or creative approach to reclamation. Examples are the establishment of wildlife habitat or riparian area, creation of wetland, voluntary reclamation on land that is not required to be reclaimed, development of public access and recreation opportunities on reclaimed land, and collection and use of native species of plants.

Winner of this award is Bonnanza Mining, Inc., located on USDA Forest Service land along Pine Creek near Halfway in northern Baker County. Mining to extract free gold from a glacial till deposit began on this property in 1986 and was completed in the fall of 1992. Reclamation began in 1988. Prior to mining, soil cover was stripped and stockpiled separately from the overburden. Because of earlier mining at the site, some of the area had no soil cover. To improve revegetation, new soil material was created by mixing sand and silt that had been separated from gravel during the mining with straw and manure obtained from nearby farms and ranches. During the reclamation, more than 5,000 conifers were planted along with numerous native plants including dogwood, black cottonwood, chokecherry, wild rose, snowberry, willows, cattails, and alder. Wetlands created at the site are now filled with thousands of frogs, and blue heron have been observed at the site. Bonnanza received this award because of its outstanding reclamation project and its willingness to address any problems identified by MLR inspectors.

Exploration Award: This award is given to an explorationist who reclaims exploration roads and drill pads to pre-mine topography, revegetates the exploration site to blend in with the surrounding vegetation, and follows established drill-hole abandonment procedures to protect ground water.

Cambiex received this award for a gold exploration site located about 5 miles east of the community of Wolf Creek in northern Josephine County. This site was in a Douglas fir forest on a steep hillside on Bureau of Land Management and Josephine County land. To reach the site, the company used bulldozers to clean out old roads and build one long road and several shorter ones. Upon completion of the exploration, the original contour of the land was restored along the long road by a backhoe. Roads built on county land were left for logging access. To minimize erosion, the surface was recontoured and left in a rough condition, and fallen branches and organic material were incorporated into the slope. Straw mulch was spread over the site. The area was not reseeded, because few grasses grow in the forest environment, and seeds already in the soil revegetated the area with native species. Cambiex was given this award for its successful reclamation on a difficult site.

Good Neighbor Award: This award is given to an operator who unselfishly works with neighbors and the community in a spirit of cooperation to reflect a positive image of the mining industry.

The award was given this year to Clackamas Sand and Gravel Company, who worked with 20 at-risk students from a local alternative high school, giving them hands-on experience in reclaiming eight acres in the Clackamas Industrial Center east of Milwaukie in Clackamas County. The students were taken to the site for four hours a day, two times a week, for six weeks. They learned about native plants, river ecology, and propagation techniques from experts and then used their newly acquired environmental education to create an artificial wetland in an abandoned gravel pit. Clackamas Sand and Gravel produced a video documenting the activities. The company's willingness to work with these students to reclaim an area earned it the Good Neighbor Award. □

Camp Carson Mine site to be reclaimed

Funding for a reclamation project located 20 miles south of La Grande, Union County, along Tanner Gulch Creek in the Wallowa Whitman National Forest was approved at the last meeting of the Strategic Water Management Group in Salem on June 14. Three agencies will work cooperatively to clean up the abandoned Camp Carson Mine site to protect critical salmon habitat in the upper Grande Ronde River. Cooperating agencies are the USDA Forest Service, which will contribute $45,000 to the project; the Bonneville Power Administration, which will contribute $20,000; and the State of Oregon Watershed Health Program, which will contribute $45,000. The Oregon Department of Geology and Mineral Industries and the USDA Forest Service will jointly do the actual reclamation work.

Design of the reclamation project is scheduled to begin immediately. The completion date is set for June 30, 1995. DOGAMI staff geologist Dan Wermiel said, "Steps must be taken immediately to protect the spawning habitat in the upper Grande Ronde River and downstream reaches from getting a heavy load of sediment from the Camp Carson area."

Gold mining at the Camp Carson Mine, one of the largest hydraulic placer gold mines in Union County, first began in 1872. Although the most intense mining took place in 1893 and 1894, mining occurred over a period of many years at the site. In the early 1980s, the operator who was mining at the site abandoned it, leaving silts, claystone, and gravels on the edge of a steep hillside. This material is being washed into Tanner Gulch Creek, which will eventually affect salmon spawning habitat. In addition, cracks that are appearing in the slope suggest that a massive landslide may be imminent. Plans to reduce the amount of sediment washed into Tanner Gulch, to stabilize the slide, and to reclaim the site include recontouring the land, revegetating the hillsides to stop runoff, dewatering the slide, and building structures to contain both the slide and sediments coming from it. □

GIS/AGI/AESE offer geowriting course

The Geoscience Information Society (GIS), the American Geological Institute (AGI), and the Association of Earth Science Editors (AESE) will cosponsor the short course "Geowriting: Guidelines for Writing and Referencing Technical Articles" at the 1994 Geological Society of America annual meeting in Seattle in October.

The morning session of the course will focus on technical report writing. As a resource and text it will use the newly revised book *Geowriting*, which was published by AGI and has gone through several editions since its first appearance in 1973. Discussion will cover organization, getting started, editing, common grammatical problems, graphic presentation of data, and a brief introduction to common software packages available for word processing and computer graphics.

The afternoon session will focus on library research and referencing: the use of library catalogs and bibliographic databases, the compilation of references, and the use of software for compiling references and bibliographies.

The short course will be given on Saturday, October 22, 1994, 8 a.m. to 5 p.m., at the Seattle Sheraton Hotel. The number of participants is limited to 35, and preregistration is required. The fee, which includes handouts and a copy of *Geowriting,* is $140 ($120 for early registration prior to August 1). For students, the fee is $99.

Contact for more information and registration is Julie Jackson, American Geological Institute, 4220 King Street, Alexandria, VA 22302; phone 703/379-2480; FAX 703/379-7563; internet email lar@aip.org.

—*GIS news release*

DOGAMI PUBLICATIONS

Open-file report presents two geothermal studies

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two geothermal studies of the Cascade Range and of Newberry volcano just east of it in central Oregon. One report provides estimates for electrical generation potential; the other report helps in determining where and how deep future exploratory drill holes should be to provide useful thermal data.

The two studies have been released as one report, DOGAMI Open-File Report O–94–7. Gerald L. Black produced the report *Geothermal Electrical-Power Generation Potential of Newberry Volcano and the Oregon Cascade Range*; and David D. Blackwell produced *A Summary of Deep Thermal Data From the Cascade Range and Analysis of the "Rain Curtain" Effect*. Preparation of the reports was funded by the Bonneville Power Administration as part of a program to identify and characterize geothermal resources in Oregon.

Both reports are based on all relevant drilling data that have been produced so far. Black's report evaluates geothermal potential on a township-by-township or, for Newberry volcano, on a section-by-section basis. Blackwell's report summarizes and evaluates data of 17 deep geothermal exploration wells from Washington to northern California and of 12 deep wells from the Newberry volcano area. While temperature gradients cannot be determined except by drilling, the evaluation of previously collected data allows more systematic planning of future exploratory wells. The significance of the "rain curtain effect," which describes the influence of shallow ground-water flow on geothermal temperature data, appears to have been overestimated in the past.

Open-File Report O–94–7 sells for $9. The order form on the back cover of this issue has detailed ordering information.

New tsunami brochure available

The Oregon Department of Geology and Mineral Industries (DOGAMI) has prepared a brochure telling Oregonians and visitors to the state what to do in case of a tsunami. Entitled "Tsunami!" and printed by Portland General Electric Company, the brochure describes the causes of tsunamis, tells what to do ahead of time to prepare for such a disaster, and gives instructions on what to when a tsunami occurs. The brochure also presents facts about other tsunamis that have affected Oregon and other parts of the world, and lists names and addresses of emergency organizations and other sources of information about both earthquakes and tsunamis.

A tsunami caused by an offshore earthquake could strike the Oregon coast just minutes after the ground shaking stops and before there is time for an official warning. The earthquake may be the only warning that a tsunami is coming. So it is important that people know of the danger and what to do to protect themselves.

Although tsunamis are infrequent, they occur often enough around the world to warrant attention and preparation. Last year, for example, a tsunami generated by an offshore earthquake hit the Japanese island of Okushiri five minutes after the earthquake, generating waves from 10 to 100 ft high. Although the tsunami devastated a city on the island, only 200 people died, because the Japanese have been trained to go inland and uphill after an earthquake, even if there is no official warning, and most of the citizens saved their lives by doing so.

The tsunami brochure is available through coastal emergency offices and other locations on the coast. Single copies may be obtained by sending a self-addressed and stamped legal-size envelope to the Nature of Oregon Information Center, Suite 177, 800 NE Oregon Street #5, Portland, OR 97232. Organizations wanting larger numbers of copies should contact the Center, phone 731-4444. □

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OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 56, NUMBER 5 SEPTEMBER 1994

IN THIS ISSUE:

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 56, NUMBER 5 SEPTEMBER 1994

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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Information for contributors

Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references). If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy (**from Macintosh systems, high-density diskette only**). Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be together at the end of the text.

Style is generally that of U.S. Geological Survey publications. (See USGS *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).

Cover photo

Historical example of Oregon stock certificate issued by the Comer Mines Company in 1912. Through 1913, President E.D. Brigham and Secretary-Treasurer M.M. Wasley, who had come from Chicago to do business in Portland, had succeeded in finding investors for about 75 percent of their capital stock of $1.5 million. Four years later, the company went out of business. Photo from Oregon Historical Society negative number ORHI 90670, manuscript 2220.

In the article beginning on page 114, Bob Whelan discusses how to evaluate mineral ventures before investing in them. □

Time's up!

As you read this, you may realize that the delivery of this issue of *Oregon Geology* also marks the deadline for the mystery photo contest of the previous issue. Announcing the winner of the contest will have to wait until yet another issue of our magazine. However, we can now at least satisfy your curiosity and tell you briefly what the picture showed: The area is in the Cascade Range, just south of the southernmost end of the Three Sisters Wilderness, in the Irish Mountain 7½-minute quadrangle. We shall tell you more about it in the next issue. —*ed*

Time's almost up!

This issue of *Oregon Geology* is the last one to show the current subscription rates and prices. **Effective October 1, 1994**, the price for a single issue of *Oregon Geology* will be $3, the subscription price for six issues (one year) will be $10, and the subscription price for 18 issues (three years) will be $22. We hope for your understanding and will do our best to continue bringing you Oregon's geology in the manner to which you have become accustomed.

You still have a chance to renew at the old prices. Remember that your renewal will go into effect only after your current subscription expires—there is no overlap and no loss. Use the renewal form on the back cover **now** and let us have your renewal at the old price—**by October 1**! —*ed*

Governing Board adopts civil penalty rules for mining violators

In a major step toward stricter control of health and safety or environmental risks posed by mining, the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI), including Chair Ronald Culbertson of Myrtle Creek, John Stephens of Portland, and Jacqueline Haggerty-Foster of Weston Mountain, adopted civil penalty rules for violations related to all mining operations other than chemical-process mining (which is covered by existing rules).

On the basis of this decision made at the Board's meeting on July 11, 1994, in Portland, DOGAMI may issue a Notice of Civil Penalty whenever mining operators do not respond to notices of violation or if the violation poses an immediate threat to the public or the environment. The new rules establish four classes of civil penalties DOGAMI may impose. Fines range from maximally $1,000 per day to $10,000 per day. □

DOGAMI drilling in Salem to collect earthquake hazard data

The Oregon Department of Geology and Mineral Industries (DOGAMI) is starting a drilling program in the Salem area to collect data that can be used to define the geology of the area and determine how sediments and bedrock will respond to seismic waves. Those data will help to develop hazard maps that show which areas are most likely to suffer damage when an earthquake occurs.

Two holes will be drilled. The first hole will be located in Bush's Pasture Park and is expected to reach a depth of about 150 ft. The second hole will be about 60 ft deep and will be drilled west of Salem at what used to be Eola County Park in the Eola Hills.

The drilling project is funded by the Oregon State Lottery and DOGAMI and is part of DOGAMI's relative hazard mapping program currently focused on urban areas in the Willamette Valley and along the coast. Information from this drilling project will be made available to the public by the end of 1995. □

The Bornite breccia pipe, Marion County, Oregon

by Barton G. Stone, Kinross Copper, P.O. Box 409, Mill City, Oregon 97360

ABSTRACT

The Bornite breccia pipe (called Cedar Creek breccia pipe in earlier literature) is a Miocene-age tourmaline-copper sulfide breccia associated with a diorite/quartz diorite intrusion in the Western Cascades, 48 mi east of Salem, Oregon. Kinross, current property owner, has successfully completed an Environmental Impact Statement, with the USDA Forest Service (USFS) Record of Decision approving construction of a 1,000-ton per day (tpd) underground copper mine on a reserve of 2.2 million tons of 2.53 percent copper, 0.57 ounces per ton (opt) silver, and 0.021 opt gold. This paper presents geologic information developed since the geochemical discovery by AMOCO in 1976.

INTRODUCTION

The Bornite breccia pipe (called Cedar Creek pipe in earlier literature) is a vertically oriented cylinder of tourmaline-copper sulfide mineralization associated with granodioritic intrusions emplaced into Sardine Formation andesites of Miocene age. The deposit is located at 2,200 ft elevation in a portion of the Western Cascades at lat 44°50'N. and long 122°15'E. Kinross Copper, current owner of the property, has identified a mining reserve of 2.2 million tons at 2.53 percent copper, 0.57 opt silver, and 0.021 opt gold. The deposit is notably deficient in pyrite, unlike many similar tourmaline-bearing breccia pipes in the Western Cascades. The primary sulfides are bornite and chalcopyrite, which constitute 99 percent of the sulfides. Trace amounts of sphalerite, wittichenite, molybdenite, and galena have been noted in mineralogical studies. The purpose of this paper is to summarize geologic studies and observations made during the period 1975 to 1993.

EXPLORATION HISTORY

The North Santiam mining district (Figure 1), in which the Bornite pipe is located, attracted mining attention in the 1890s, but most of the production was intermittent between 1915 and the 1930s. The total production was very small, amounting to $10,554 over the 50 years between 1880 and 1930 (Callaghan and Buddington, 1938). This production was only one percent of the total production of the seven Cascade districts described in Callaghan and Buddington (1938). Their work drew attention to the close relationship of the mining camps to small dioritic intrusions and the zonal nature of metals in camps like the North Santiam, where a central zone of chalcopyrite veins (Figure 2) was surrounded by a zone of more complex veins, according to J.E. Allen, Portland State University (personal communication, 1992). Allen was the geologic field assistant on the Callaghan-Buddington investigation.

The porphyry copper boom of the early 1970s brought the district to the attention of AMOCO Minerals: The company had done a literature search that indicated some favorable geologic features in the district. As a followup, AMOCO then conducted a reconnaissance mapping project and staked the claims over the Bornite pipe as part of that project. An initial pass noted a number of tourmaline-bearing breccia pipes and dioritic intrusions with pyritic haloes in the next valley to the northeast of the Bornite pipe but overlapping into the Cedar Creek valley (Stan Dodd, personal communication, 1991). Claim staking, followed by geochemical and geophysical surveys in 1975 and 1976 (Figures 3 and 4), led to the identification of eight soil samples that were anomalously high in copper. Followup magnetic studies showed a low in the vicinity of the high-copper soils (Figure 5). This discovery, coupled with rock chip geochemistry, gave AMOCO personnel a drilling

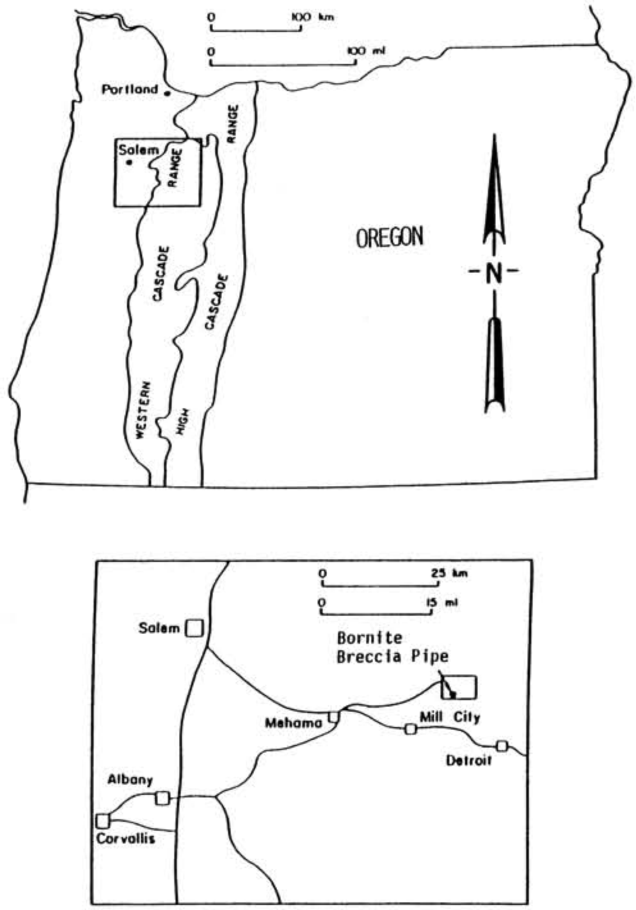

Figure 1. Index map of the North Santiam district and location of the Bornite breccia pipe. Figures 1–11 from Stone (1992).

target. Diamond core hole CC 1 was drilled at a – 45° angle but lacked mineralization to explain the geochemistry or the magnetic signature. The drill mast was turned vertically and at 325.7 ft intersected a coarse-grained quartz-chlorite-tourmaline-sulfide breccia that averaged 92 ft of 6.89 percent copper (J. Matlock, unpublished data, 1991). Drilling continued until 1979, but AMOCO quickly realized it did not have a major porphyry discovery but a small high-grade breccia pipe. From 1980 to 1988, AMOCO performed limited drill programs to satisfy the annual claim assessment requirements. Through 1988, AMOCO Minerals (and its successor, Cyprus Minerals) drilled a total of 17,865 ft in 20 core holes and one conventional rotary hole (Figure 6).

Kinross, under its earlier name Plexus, Inc., acquired control of the breccia pipe in a trade agreement with Cyprus Minerals in 1989 and renamed it the Bornite pipe because of the abundance of that copper sulfide mineral. Since then, the company has drilled an additional 16,419 ft of core in 25 angle holes to confirm the geometry and grade estimates (Figure 7). Plexus conducted additional geophysical studies, using a number of contractors to develop a breccia pipe model signature for continued exploration in the district (Figure 8). In July 1991, Kinross filed a Plan of Operations with the USDA Forest Service to initiate an Environmental Impact Study (EIS). In April 1993, the USFS published the Final EIS and Record of

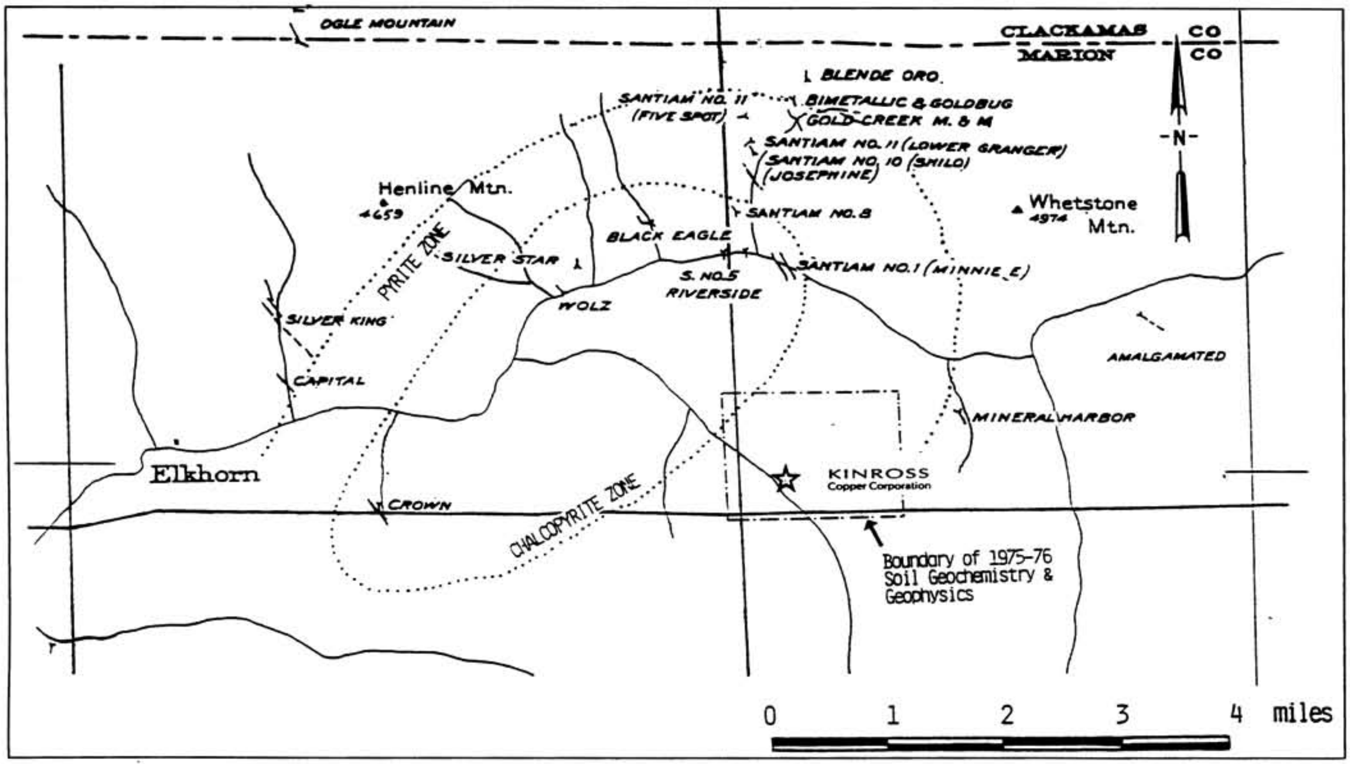

Figure 2. Sketch map of the North Santiam district in 1930–1931, showing location of mining camps and metal zones. After Callaghan and Buddington (1938).

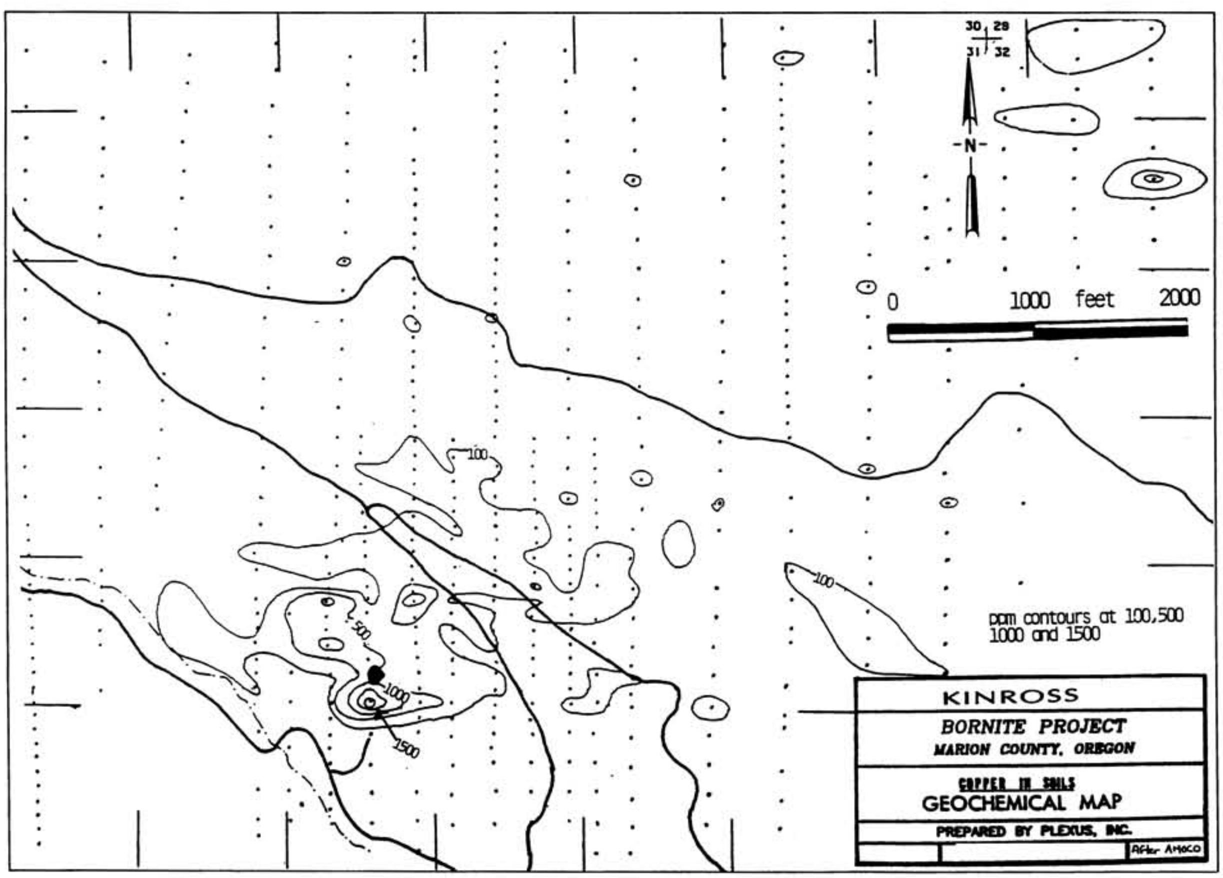

Figure 3. Geochemical survey map showing copper in soils at Bornite project. Contour lines outline 100, 500, 1,000, and 1,500 parts per million (ppm) copper. Heavy lines are roads; dotted lines mark survey grid.

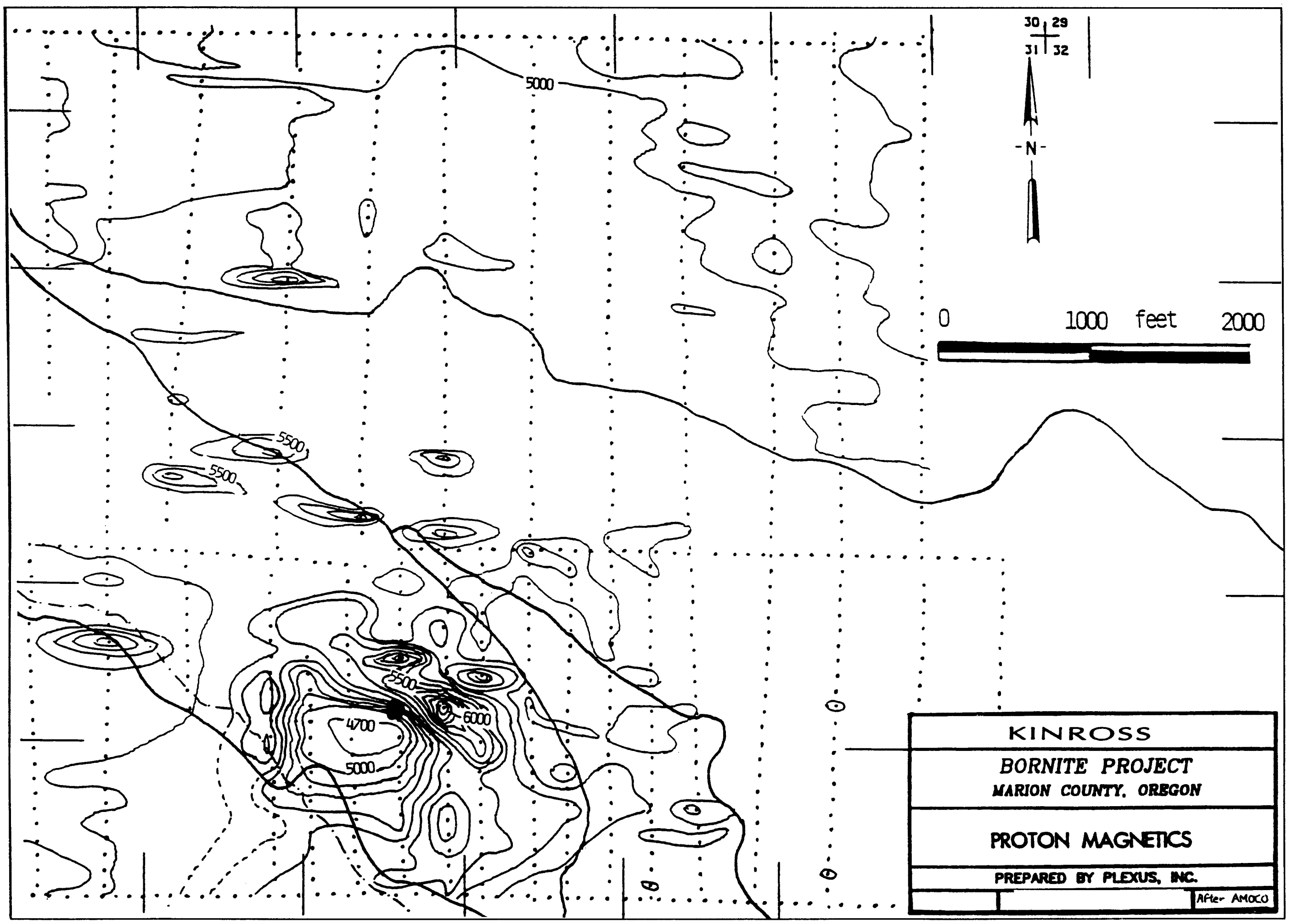

Figure 4. Magnetic survey map of Bornite project, showing gamma contour lines at contour intervals of 100 gammas. For absolute values, 50,000 gammas are to be added to each map value. Dotted lines mark survey grid.

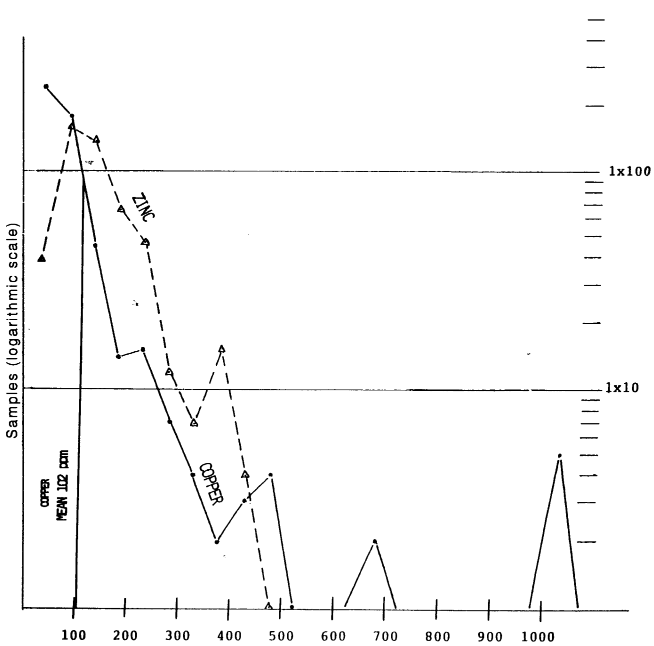

Figure 5. Bornite project copper and zinc soil geochemistry, showing ppm versus number of samples (on logarithmic scale).

Decision to allow the development of a 1,000-tpd underground copper mining operation. Kinross is currently awaiting the final permit from the National Pollution Discharge Elimination System (NPDES) and a decision by the State of Oregon on the use of water.

REGIONAL GEOLOGY

The sketch map in Figure 9 shows the geology of the North Santiam area. Cummings and others (1989) conducted extensive work in the volcanic stratigraphy of the North Santiam mining district. The volcanic stratigraphy is characterized by its complexity in both the horizontal and vertical dimensions. Two stratigraphic sequences have been recognized in the vicinity of the Bornite pipe. The lower sequence has been assigned to the Sardine Formation (Thayer, 1937; Peck and others, 1964) and occurs from the bottom of stream valleys to an elevation of approximately 3,950 ft. The upper sequence overlies the lower sequence across an erosional unconformity. The upper sequence is at least 1,300 ft thick and underlies the ridge crests of the area. This upper sequence includes the Elk Lake formation (McBirney and others, 1974), and the High Creek ignimbrite (Dyhrman, 1975; Hammond and others, 1980). This sequence was deposited on a moderate relief surface eroded into the Sardine Formation.

The Sardine Formation includes andesite flows, andesite lapilli, lithic tuffs, sparse sediments, and intrusions. All lithologies have had some degree of superimposed alteration, which often obscures primary igneous textures. In the eastern part of the North Santiam district, Sardine Formation stratigraphy was divided into Unit A and

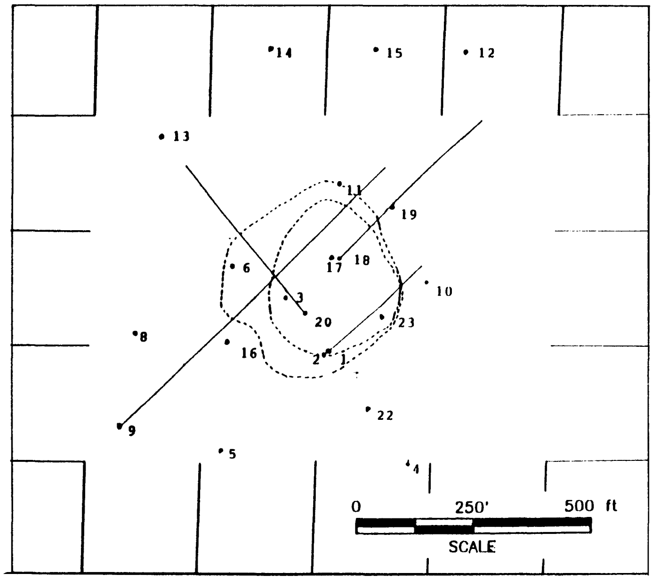

Figure 6. Drilling performed by AMOCO during 1976–1988 at the Bornite pipe, showing locations of 20 core holes and one rotary hole. Not all holes are located within the limits of this map area.

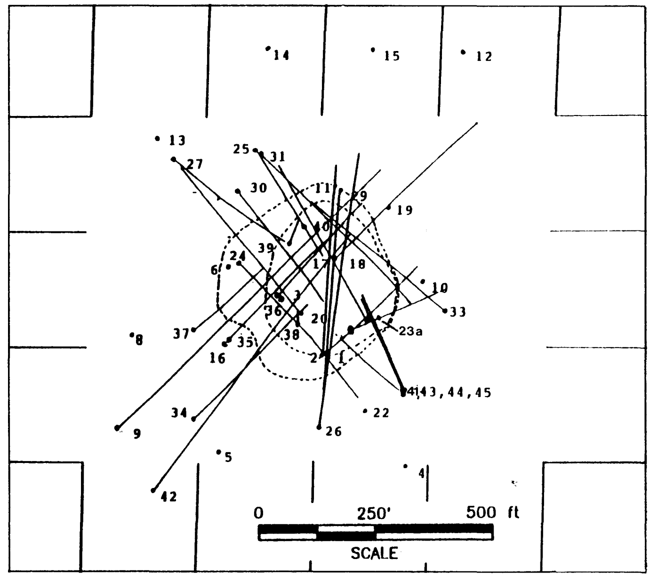

Figure 7. Kinross (formerly Plexus) drilling during 1989–1992, superimposed on Figure 6. Not all holes are located within the limits of this map area. Note general confirmation of earlier findings.

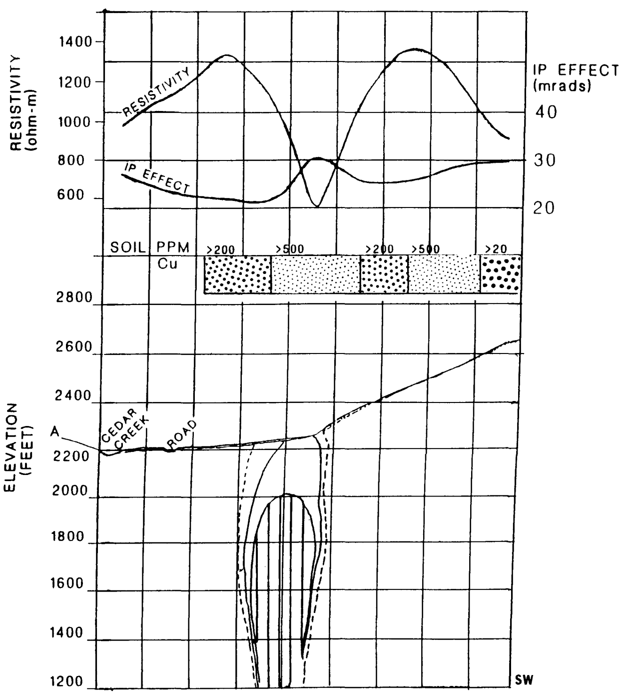

Figure 8. Signatures of induced-polarization (IP) effect and resistivity measurements over the Bornite breccia pipe (top) in relation to soil sample data (below) and the underlying cross section of the same breccia pipe.

Unit B by Pollock (1985). The two units were distinguished by their relative proportions of fragmental rocks and flows. Unit A, the lower unit, consists of andesitic tuffs and tuff breccias, with individual cooling units ranging from 35 to 150 ft in thickness; and Unit B consists of porphyritic andesite flows interbedded with lapilli tuffs. Along Cedar Creek in the vicinity of the Bornite pipe, Unit B is approximately 1,800 ft thick.

INTRUSIVE ROCKS

Two major intrusive rock types have been described in the North Santiam district (Olson, 1978). The first consists of fine-grained dike rocks ranging in composition from basalt to rhyodacite and probably correlative with the Sardine Formation. The second, younger type of intrusions consist of coarser-grained dioritic rocks. These rocks have been subdivided into three main types: (1) Microdiorite; (2) medium- to coarse-grained diorite (Ruth diorite); and (3) a composite intrusive unit (Hewlit granodiorite) consisting of medium- to coarse-grained tonalite, granodiorite, and quartz monzonite.

The diorites and quartz diorites in the vicinity of the Bornite pipe are thought to be correlative with the Hewlit granodiorite, exposures of which have been dated by K-Ar methods at 13.4±0.9 Ma (Power and others, 1981). In the Ruth Mine area, 3.5 mi east-northeast of the Bornite pipe, sulfide deposition occurred at depths exceeding 2,830 ft (900 m) (Pollock, 1985).

Four miles to the southwest of the Bornite pipe, a 5-km (3-mi)-wide zone of dikes extends northwest from the Detroit stock through Rocky Top (Curless, 1991). Intrusive rocks within the adjacent Sardine Creek and Rocky Top areas have mineralogical, textural, and chemical features similar to the spatially and temporally related Detroit stock. The Detroit stock, 7 mi south of the Bornite pipe, is of intermediate composition, having at least five stages of intrusion into volcanic rocks at least as young as early Miocene age (Curless, 1991). Curless' work on the plutonic rocks in the Rocky Top and Detroit Dam area suggests that plutonic hornblende granodiorites were emplaced at a minimum depth of approximately 1,000 m (3,300 ft), whereas the older quartz diorites were emplaced at shallower levels (Curless, 1991). Walker and Duncan (1989) report a whole-rock K-Ar age of 9.94±0.18 Ma for a sample from the Detroit stock. A sample of hydrothermal sericite in the Bornite pipe yielded a K-Ar age of 10.1±0.4 Ma (Winters, 1985), which suggests synchronous emplacement with the Detroit stock to the south.

BORNITE PIPE GEOLOGY

The geometry of the pipe is that of a mineralized ring of copper sulfides (60 percent chalcopyrite, 39 percent bornite; Winters, 1985) up to 450 ft in diameter and 1,200 ft vertically (Figures 10 and 11). Minable widths of the ring approach 30 ft on average. This 30-ft

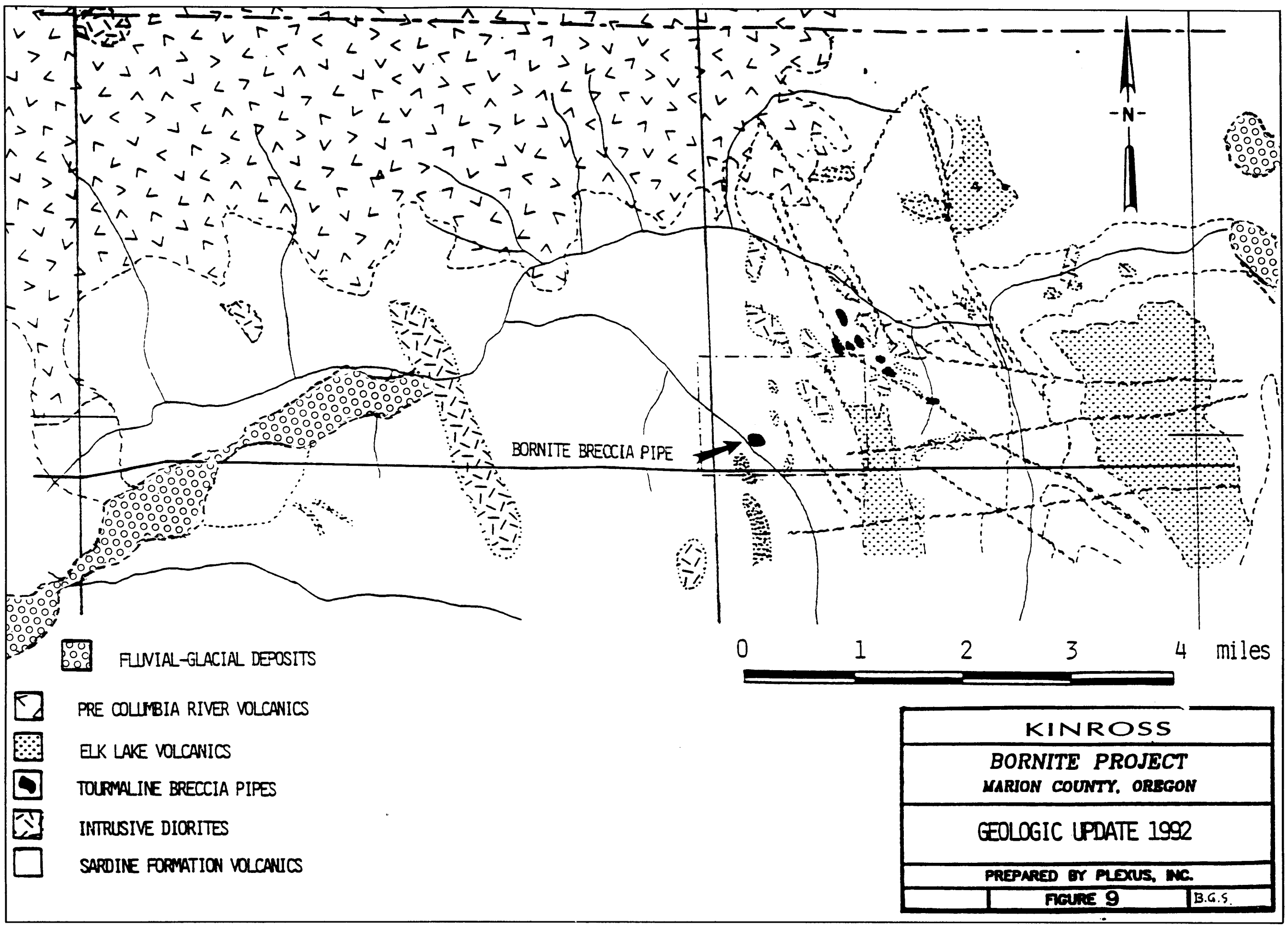

Figure 9. Geologic sketch map of Bornite project area (marked by dot-dash rectangle). Straight dashed lines mark contacts; lines of wiggly dashes indicate faults.

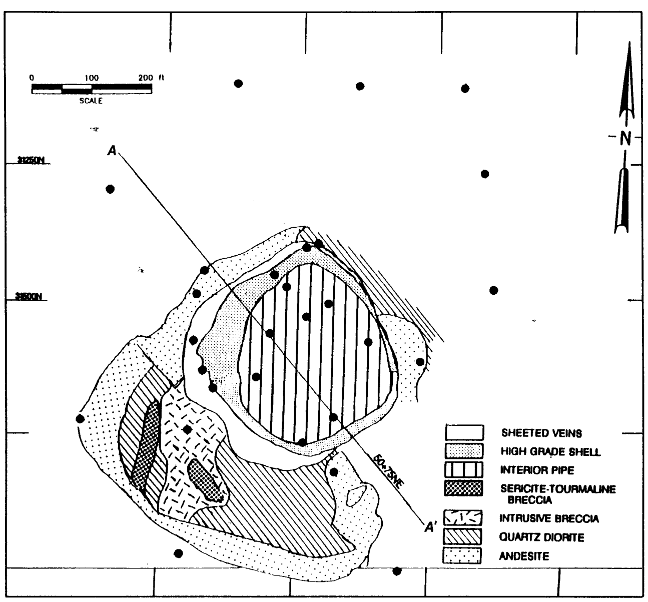

Figure 10. Geologic elevation-level plan of the Bornite breccia pipe at an elevation of 1,800 ft. Dots mark drill-hole piercing points. Line A–A′ indicates orientation of cross section shown in Figure 11.

annular body of quartz-sericite-tourmaline-sulfide surrounds a low-grade to unmineralized diorite to quartz diorite core. The outer edge of the ring has the highest metal values.

Although earlier work suggested formation of the deposit by an intrusive diorite moving towards the surface and creating a strongly brecciated margin that was subsequently mineralized, more recent work suggests that large portions of the core diorite are as brecciated as the sulfide ring, and the only difference is the lack of copper-sulfide mineralization in the core of the brecciated zone.

Several textural types of breccia occur within the Bornite pipe. The most distinctive is a lath breccia where the long dimension of a fragment exceeds the narrow dimension by at least 4:1. The appearance is similar to a shingle breccia in sedimentary rocks and has been called shingle breccia by other igneous-breccia workers (Sillitoe, 1985). Similar textures have been described associated with tourmaline breccia pipes and granodiorite intrusions in the area of Stoney Creek, 1.5 mi northeast of the Bornite pipe (Cummings and others, 1989). Arrangement of the rectangular clasts ranges from parallel to random irregular. Identical breccias may or may not contain copper mineralization. Some of the lath fragments were mineralized with quartz veins prior to being incorporated in the lath breccia, as veins within breccia clasts are truncated at the edge of the fragment (drill hole CC-43). Frequently the parallel orientation of laths gives the appearance of closely jointed rock which has been slightly swelled, and chlorite/sericite/tourmaline fills the joints as a network of veinlets. A long intercept through the diorite may have dozens of discrete lath breccia zones with identical

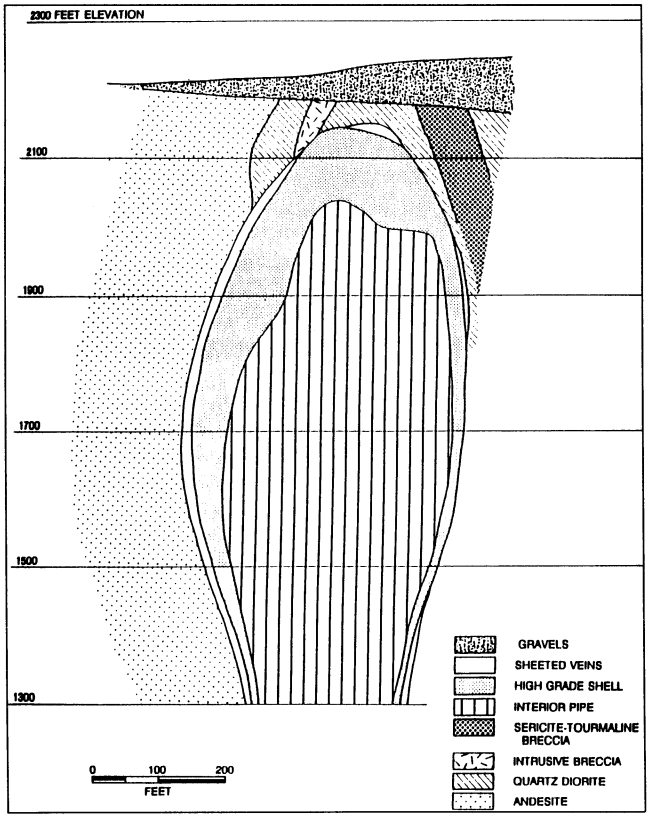

Figure 11. Geologic cross section of the Bornite breccia pipe along line shown in Figure 10 as A–A′.

massive diorite on either side. The lithology of the lath clasts is the same as the unbrecciated diorite on either side.

A second type of breccia is the large-fragment breccia that is clast supported with fragments up to 6 in. long. Matrix material is predominantly crystalline quartz with lesser amounts of tourmaline, sulfide, sericite, and apatite. Quartz in these zones has vug cavities with euhedral quartz and apatite crystals up to 1 in. in diameter. A better description of this would be a vein breccia with the quartz and related crystalline minerals separating the fragments.

Numerous geologists have examined the core over the past 16 years. The mineralized rock is essentially a brecciated diorite with varying amounts of quartz, chlorite, sericite, tourmaline, bornite, and chalcopyrite. Consequently, all sorts of lithologic names have been assigned to what are actually, at the hand-specimen level, variable degrees of alteration.

ALTERATION

Propylitic alteration is ubiquitous in the Cedar Creek valley and in all outcrops surrounding the Bornite pipe. It is weakly pervasive but increases near intrusions, faults, fractures, and vein systems. The alteration assemblage is characterized by a secondary mineral assemblage of epidote ± chlorite ± quartz ± sericite ± calcite ± albite ± hematite ± magnetite ± pyrite, that is not destructive of original textures. Hand specimens show various shades of pistachio and olive green, dependent on the relative amounts of epidote and chlorite. Generally, calcite and epidote replace the plagioclase, while chlorite, calcite, and epidote replace primary mafic minerals. Veinlets containing quartz, calcite, and epidote are common in the propylitically altered rocks. Within the Bornite pipe, calcite veinlets appear to be the final mineralizing event.

In my porphyry copper experience in the western United States, potassic alteration is most commonly associated with strong silicification and is characterized by the conversion of minerals to secondary sericite, potassium feldspar, and biotite. The lack of biotite and potassium feldspar at Bornite and the difficultly of separating the sericite associated with phyllic alteration from what is often associated elsewhere in porphyry copper systems with potassic alteration have caused us to assign the sericite to the phyllic alteration zone. Massive crystalline clusters of bright silver sericite up to 0.10 in. in cross-sections of individual plates are common in the Bornite deposit. Unlike the Black Jack pipe owned by Kinross in the Washougal mining district of Washington, the Bornite pipe lacks obvious potassium feldspar or biotite minerals.

Phyllic alteration is associated with silicification and tourmalinization throughout the Bornite pipe—as texturally destructive sericite replacement of fragments, selvages on veins, and broad haloes on small faults and fractures. In drill core it is ubiquitous as bleached texture-destructive alteration haloes, which, in the diorite, grade outward into the argillic zone where swelling clays preferentially replace plagioclase phenocrysts.

Silification is most commonly defined by the development of crystalline quartz veins with crystal-lined vugs and cavities. Individual quartz crystals up to 1 in. in diameter have been observed in some of these vugs and veins. Similar-size apatite crystals have been observed in the same locations. Multiple periods of quartz mineralization are observed in the cross-cutting relationships found in drill core. At 393.5 ft in drill hole CC-43, a 0.4-in. quartz veinlet with molybdenite centerline and traces of chalcopyrite and bornite is cut perpendicularly by a 0.04-in. chalcopyrite veinlet that contains chalcopyrite only in the portions cutting the diorite. In drill hole CC-45 at 306 ft, a steep 0.08-in. quartz-chlorite-sericite veinlet with bornite centerline cuts and offsets a 0.04-in. quartz vein with bornite centerline. Selvage wall-rock bleaching appears to be mostly associated with the narrower, later veinlet. In drill hole CC-42 at 299 ft., a 0.4-in. vuggy quartz vein is cut by a 0.04-in. chalcopyrite veinlet that is in turn cut by a 0.08-in. carbonate-quartz veinlet. At 201 ft in drill hole CC-43, a 0.20-in. gray quartz veinlet crosscuts a 0.25-in. quartz-chlorite-tourmaline-chalcopyrite veinlet. Quartz veining occurred prior to some of the brecciation, as evidenced by diorite fragments within breccia that contained two ages of quartz veins prior to brecciation (drill hole CC-43 at 477 ft).

Tourmalinization is ubiquitous and displays numerous characteristics in its occurrence. Most commonly, it is in the form of jet-black radial clusters associated with the highest temperature quartz veins. Very commonly, the quartz vein selvages consist of tourmaline altering to a greenish chlorite (drill hole CC-42). Another common occurrence is in the form of large black clots several inches across in the middle of medium-grained diorite, as if they were large xenoliths. Frequently, the bornite and chalcopyrite appear to be preferentially concentrated within the tourmaline clots. Sericite frequently appears to replace the fibrous tourmaline needles, and in places it may be pseudomorphous in the rosette sites. The strong radiating acicular habit of the tourmaline is acquired by its replacement minerals hematite and sericite (drill hole CC-42 at 930 ft). In the clotted form, the tourmaline aggregates form up to 10 percent of the rock mass (drill hole CC-45). Often, the physical appearance of the clots is that of oil drops or paint splatter on the core surface. Tourmalinization without associated sulfide minerals is quite common, even outside the breccia pipe limits, which may indicate more than one period of tourmalinization.

FLUID INCLUSION STUDIES

Microthermometric measurements of 90 samples from eight drill holes were taken by Winters (1985), who distinguished four types of inclusions based on different phase assemblages (Figure 12):

- Type I: Vapor and liquid;
- Type II: Vapor, liquid, and halite (NaCl);
- Type III: Vapor, liquid, NaCl, and sylvite (KCl);
- Type IV: Vapor, liquid, NaCl, KCl, and one or more other solid phases.

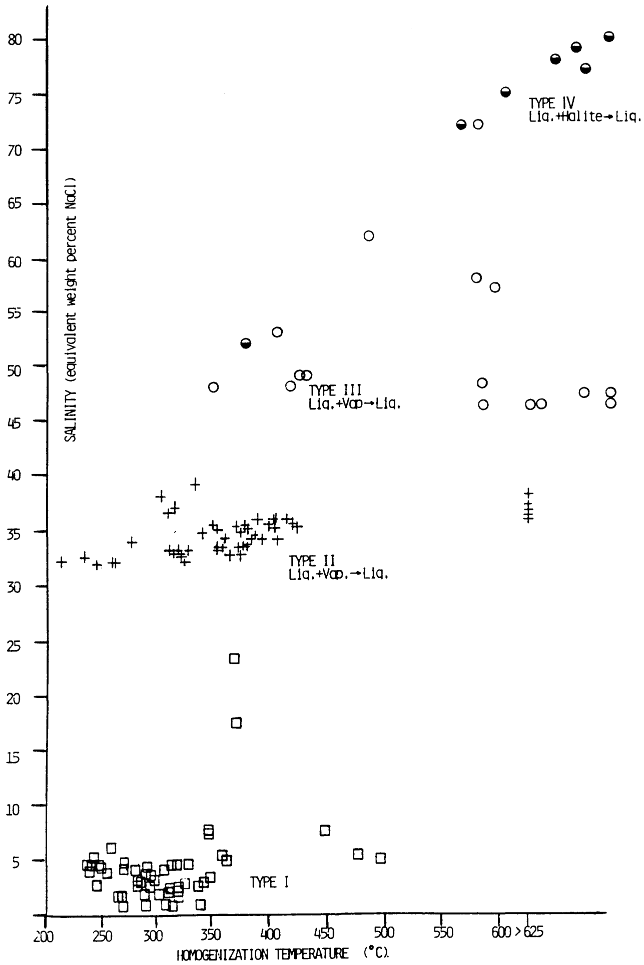

Figure 12. Fluid inclusion data on Bornite breccia pipe, plot of homogenization temperature (°C) versus salinity (equivalent weight percent NaCl). Data from Winters (1985). Inclusion types: Type I = open squares; Type II = crosses; Type III = open circles; Type IV = partially filled circles.

Tentative identification of two of the unknown solid phases were gypsum and anhydrite. Results of the homogenization studies showed the following (summarized in Table 1):

Type I inclusions

A total of 85 measurements in quartz inclusions and 28 in apatite indicated a temperature range of 150° to 300°C for apatite and 225° to 500°C for quartz. No relationship to depth could be determined from homogenization temperatures or salinities.

Type II inclusions

A total of 72 Type II inclusions were examined. All homogenized to liquid by vapor disappearance, with the majority between 300°C and 425°C. Salinity ranged from 31 to 39 equivalent weight percent NaCl. No correlations between homogenization temperature, salinity, and depth were found.

Type III inclusions

A total of 31 Type III inclusions were observed. Seven homogenized by halite disappearance, the remainder by vapor disappearance. Homogenization temperatures ranged from approximately 325°C to >625°C. Total salinities of Type III inclusions are 45 to 80 percent but do not appear to be related to depth.

Type IV inclusions

Measurements were made on 45 Type IV inclusions. Homogenization temperatures ranged from 375°C to 525°C. Heating was continued to 625°C to observe the behavior of anhydrite. No correlation was found between homogenization temperature, salinity, and depth.

Table 1. *Summary of the results of fluid inclusion studies*

Type	Temperature (°C)	Composition (equivalent weight percent NaCl)	Pressure (bars)
I	225–500	0–23	220–800
II	212– +625	31– +65	20–875
III	327– +625	45–80	50–175
IV	384–529	n.d.	n.d.

The results of fluid inclusion study suggest three generations of inclusions indicative of three different hydrothermal events (Winters, 1985). Core logging and thin section studies support multiple phases of mineralization (Summers, 1991). Summers' work showed homogenization temperatures of 224° to 300°C for Type I inclusions with salinities of 1.2 to 5.1 weight percent NaCl equivalent associated with sulfide-bearing veins. Type III inclusions homogenized at >490°C, the upper limit of Summers' microthermometry equipment, and were associated with quartz-tourmaline veins. Minimum pressure of formation was estimated at >300 bars.

SULFUR ISOTOPE STUDIES

The four naturally occurring isotopes of sulfur fractionate in response to physical and chemical processes acting upon them. The most abundant of the isotopes are ^{32}S and ^{34}S. Compositions are given by conventional per mill (parts per thousand) notation with respect to ^{34}S in the meteorite standard: positive values represent enrichments of ^{34}S in per mill, and negative values represent depletions of ^{34}S in per mill, relative to the standard. In hydrothermal systems, these fractionations are preserved as small differences between the isotopic compositions of coexisting sulfide minerals and large differences between coexisting sulfate and sulfide minerals (Summers, 1991). Summers' work looking at sulfides from a variety of Cascade breccias did not include any isotope samples specifically from the Bornite breccia pipe, but Cyrus Field of Oregon State University has documented the values shown in Table 2 below from the Bornite pipe (personal communication, 1994):

Table 2. *Bornite pipe sulfur isotope data by Cyrus Fields (unpublished data, 1994)*

Drill hole	At depth (ft)	Description	$\delta^{34}S$ percent
CC-3	520	Chalcopyrite veinlet; bornite in veinlet	+4.19 +5.03
CC-3	500	Chalcopyrite in breccia; bornite in breccia	+1.65 +4.77
CC-2	796	Chalcopyrite in breccia; bornite in breccia	+4.58 +3.94
CC-17	1,600	Chalcopyrite	+4.85
CC-2	362	Bornite in breccia	+3.81
CC-2	382	Chalcopyrite in breccia bornite in breccia	+4.10 +3.90

These values are consistent with a magmatic sulfur source in hydrothermal fluids dominated by a reduced sulfur species (S^{2-}, HS^-, H_2S).

STRUCTURE

The geology of the Bornite pipe is obscured by a glacial-colluvial cover of coarse sandy gravel up to 140 ft thick. Drill site excavations on the north side have exposed the top portion of the tourmaline-sulfide breccia. The field evidence indicates a fine-grained, clay-rich till layer approximately 6 in. thick immediately on top of fresh sulfides. Oxidation of the sulfides extended only 2 in. below the till, indicative of a relatively impermeable barrier to downward migrating meteoric water.

Mapping of joint patterns at the outcrop and in the Cedar Creek river channel on the south side show that the dominant orientation of joints is N. 20°–30° W. The district photo-linear pattern for the area shows the predominant orientation of N. 40°–50° W. (Venkatakrishnan and others, 1980) (Figure 13). Small gouge and brecciated structural zones occur throughout all core holes but are minor in quantity, as is reflected by high recovery and high RQD values for all holes.[1] The orientation of these minor structures may be expected to mirror surface patterns of structures, but final details must await development of the deposit. Projection of ore contact boundaries and grade over hundreds of feet with validity checks by subsequent drilling suggests that structural offsets within the breccia pipe are minor.

[1] Recovery and rock quality designation (RQD) measure quality and structure of rock. In simplified terms, recovery is the percentage of core length recovered from the total length of a drill run; RQD is the percentage of core consisting of pieces 4 in. or longer in such a run.

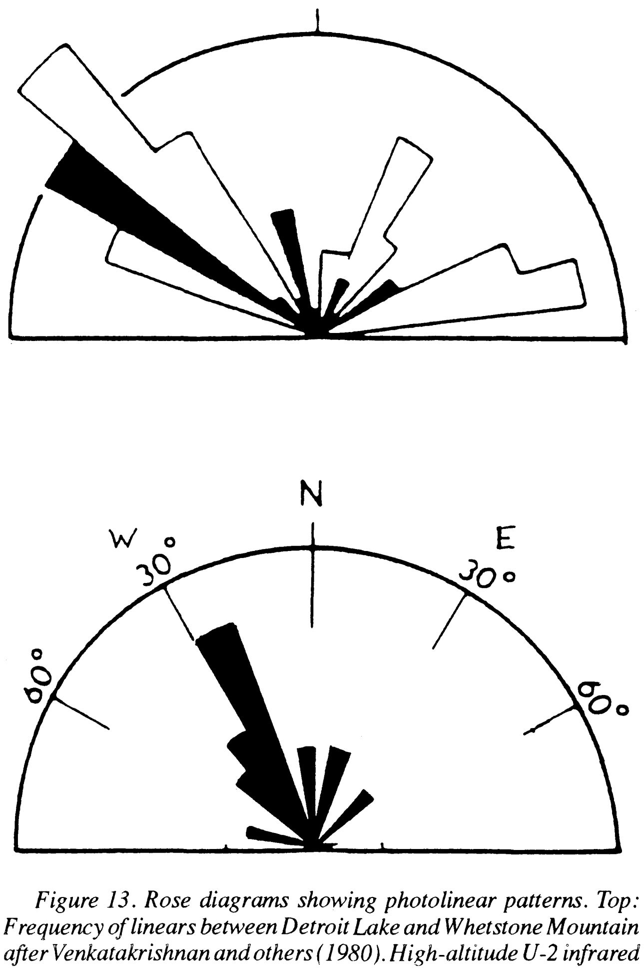

Figure 13. Rose diagrams showing photolinear patterns. Top: Frequency of linears between Detroit Lake and Whetstone Mountain after Venkatakrishnan and others (1980). High-altitude U-2 infrared linears shown as open radials; side-looking radar (SLAR) radials are darkened. Bottom: Joint frequency of Bornite breccia pipe and adjacent Cedar Creek areas.

GEOCHEMISTRY

The discovery of the Bornite breccia pipe was the result of the application of soil geochemistry prospecting technology in 1976, which identified B-horizon copper values exceeding 20 times background. The pipe has an obvious copper signature as well as a less developed molybdenum signature in soils. Construction of monitoring wells in 1991 by Kinross has led to the analysis of water in both bedrock and colluvium on a quarterly basis. The boron content of the bedrock water is the only element that shows a spatial relationship to the breccia pipe. Wells closest to the pipe have the highest boron values (in range of 0.1 ppm B).

Hundreds of assays on core provide ranges to trace element geochemistry as shown in Table 3.

Table 3. *Trace element geochemistry of the Bornite breccia pipe*

Element	General range (ppm)	Maximum value (ppm)
Lead (Pb)	50–150	2,000
Zinc (Zn)	150–500	14,500
Molybdenum (Mo)	20–100	8,000
Bismuth (Bi)	50–200	2,600
Arsenic (As)	15–250	2,600
Antimony (Sb)	1–20	450
Mercury (Hg)	<10–20	3

The sulfide composition of the breccia pipe consists of 60 percent chalcopyrite and 39 percent bornite (Winters, 1985), while the remaining sulfides total 1 percent. Tetrahedrite is the arsenic/antimony sulfosalt found in some vugs and cavities in the copper zone. Gold and silver occur as electrum grains in bornite with dimensions up to 0.08 in. across (Plexus, unpublished data, 1989). Sphalerite and galena appear to be associated with later stage carbonate mineralization and not the copper sulfide mineralization (Summers, 1991).

WHOLE ROCK CHEMISTRY

Twenty samples were sent for whole rock analysis by Bondar-Clegg at the company's Toronto lithology laboratory, where borate fusion and induction coupled plasma (ICP) methods were used (Table 4). The high copper content of many of the mineralized breccia samples caused total values of major oxides and loss on ignition (LOI) to be substantially lower than 100 percent. Three samples represent the quartz diorite intrusion, four samples the host andesite, and the remaining 13 samples the mineralized breccia. Overall mineralization effects suggest a decrease in CaO, Na_2O, and SiO_2 compared to the host andesite and intrusive diorite, but an increase in Fe_2O_3, MgO, K_2O, MnO, and copper, the economically most important. Table 5 presents the statistics for the economic metals copper, silver, and gold in the assay record of all drillholes in the Bornite pipe.

CONCLUSION

Petrographic, textural, fluid inclusion homogenization, and geochemical studies indicate that the Bornite breccia pipe was the locus of multistage mineralization leading to the economic concentration of copper sulfides. The time span involved in the events of the hydrothermal alteration is as yet unknown, as is the mechanism of formation of a cylinder of sulfide mineralization. The author's experience with chalcopyrite-magnetite concentration at the cúpola of a quartz monzonite porphyry intrusion in the Yerington pit (Lyon County, Nevada) suggests a possible similar mode of formation wherein the rising diorite created a fracture zone of cylindrical proportions above an intrusive cupola. The fracture zone became the depositional site for volatiles including copper emanating from the cooling magma.

Table 4. *Whole-rock analyses of samples from the Bornite breccia pipe, by Bondar-Clegg Laboratories*

HOLE NO	SAMPLE	FOOTAGE	ROCK TYPES	Elements											Elements								
				SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	BaO	CaO	Na_2O	K_2O	LOI	Cr_2O_3	P_2O_5	Total	S Tot	Pb	Cd	Hg	As	Cu
				Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Pct	Ppm	Ppm	Ppm	Ppm	Ppm
CC-17	18752	484	Quartz Diorite	63.91	0.55	14.98	4.73	0.47	2.60	0.077	3.80	2.66	1.28	4.99	0.02	<0.03	100.07	0.11	473	3.5	0.132	1.2	1874
CC-17	18753	888	Mineralized Breccia	68.47	0.44	12.10	5.05	0.26	2.36	0.057	2.77	0.66	2.16	4.41	0.03	0.27	99.04	0.03	69	1.7	0.107	0.7	148
CC-17	18754	1727	Quartz Diorite	64.02	0.39	13.92	4.56	0.39	1.72	0.045	3.89	0.16	3.25	5.48	0.02	<0.03	97.84	0.17	114	0.3	0.084	2.2	1473
CC-18	18802	238	Andesite	65.68	0.58	14.80	5.65	0.06	2.14	0.033	4.07	3.06	1.06	1.85	0.02	<0.03	99.00	0.18	14	<0.2	0.118	1.8	1603
CC-18	18803	294	Quartz Diorite	66.15	0.51	14.41	3.51	0.18	1.94	0.025	3.37	2.87	0.89	4.68	0.03	0.12	98.68	0.04	7	<0.2	0.070	0.6	433
CC-18	18804	24	Mineralized Breccia	69.29	0.60	10.39	7.71	0.20	1.50	0.047	0.70	0.07	2.64	5.76	0.04	<0.03	98.95	2.10	32	0.3	0.104	50.0	24500
CC-18	18805	106	Mineralized Breccia	59.07	0.69	11.62	10.88	0.51	1.78	0.031	0.83	0.05	2.73	7.59	0.04	<0.03	95.82	3.20	52	3.8	0.123	877.7	34100
CC-28	19626	178	Mineralized Breccia	59.12	0.69	16.14	6.63	0.21	1.76	0.074	0.50	0.08	4.67	6.06	0.02	<0.03	95.95	0.75	70	<0.2	0.011	7.2	15934
CC-28	19627	243	Mineralized Breccia	63.50	0.89	13.73	6.79	0.17	2.05	0.054	0.47	0.09	3.73	6.31	0.03	<0.03	97.81	0.76	16	<0.2	0.019	23.2	8114
CC-30	17048	263	Andesite	65.22	0.58	14.83	5.11	0.15	1.22	0.070	1.50	0.13	4.07	4.95	0.03	<0.03	97.86	1.50	23	0.3	0.068	8.7	17932
CC-30	17049	321	Mineralized Breccia	68.28	0.48	11.24	6.24	1.10	1.59	0.052	0.50	0.07	3.03	4.63	0.03	<0.03	96.24	2.27	54	2.4	0.099	3.4	37600
CC-30	17050	564	Mineralized Breccia	55.40	1.01	12.65	8.74	0.80	5.24	0.055	3.45	0.12	1.99	7.14	0.03	<0.03	96.63	0.41	139	0.4	0.072	1.4	8941
CC-32	16887	613	Mineralized Breccia	39.57	0.95	13.15	24.47	0.88	5.18	0.014	1.46	0.04	0.78	6.58	<0.01	<0.03	93.07	4.86	46	1.2	0.031	27.0	48800
CC-32	16888	636	Mineralized Breccia	42.16	0.92	15.73	13.30	0.83	5.91	0.044	5.52	0.04	2.22	6.51	0.02	<0.03	93.20	2.87	6920	68.8	0.054	5.7	35700
CC-42	16760	307	Andesite	54.27	0.92	23.37	2.34	0.04	1.40	0.029	4.65	6.61	1.47	3.62	0.01	<0.03	98.73	0.13	4	<0.2	0.088	5.0	2013
CC-42	16761	674	Andesite	68.00	0.42	14.03	2.95	0.17	1.39	0.029	3.35	2.59	1.97	4.49	0.02	<0.03	99.41	0.15	4	<0.2	0.113	1.6	1905
CC-42	16762	705	Mineralized Breccia	55.94	0.70	14.25	7.34	0.29	4.00	0.044	3.03	0.61	2.69	7.02	0.03	<0.03	95.94	1.00	53	1.9	0.085	1.6	21600
CC-42	16763	742	Mineralized Breccia	49.47	0.53	11.48	14.34	0.73	5.12	0.029	3.85	0.04	1.36	10.44	0.03	<0.03	97.42	1.69	302	3.3	0.097	6.8	17187
CC-44	16920	335	Mineralized Breccia	32.27	0.50	18.43	19.20	0.57	4.95	0.092	0.92	0.03	2.18	18.21	0.02	<0.03	97.37	1.40	75	2.5	0.011	8.6	19780
CC-44	16921	393	Mineralized Breccia	71.74	0.57	14.42	3.54	0.08	1.48	0.064	0.46	0.24	2.83	3.59	0.03	0.23	99.27	0.04	13	<0.2	0.068	4.5	327

Table 5. *Bornite summary assay values. Copper values in percent, silver and gold values in ounces per ton*

	ALL ASSAYS			HIGH GRADE SHELL		
	COPPER	SILVER	GOLD	COPPER	SILVER	GOLD
Number of Assays Determined	2760	2724	2708	264	264	264
Number of Assay Values Trace	2665	2335	652	264	264	264
Maximum	23.48	5.43	0.3780	23.48	5.43	0.2280
Minimum	0.00	0.00	0.0000	0.26	0.030	0.0000
Range	23.48	5.43	0.3780	23.22	5.40	0.2280
Total	1732.01	432.043	11.0090	940.23	187.93	6.6540
Mean	0.6275	0.1586	0.0041	3.5615	0.7119	0.0252
Variance	2.042	0.1347	0.3595 E-03	8.945	0.6474	0.001995
Standard Deviation	1.429	0.3670	0.1896 E-01	2.991	0.8046	0.04467
Geometric Mean	0.1955	0.0607	0.0071	2.6904	0.3848	0.0135
	SHEETED VEIN			INTERIOR PIPE		
	COPPER	SILVER	GOLD	COPPER	SILVER	GOLD
Number of Assays Determined	113	113	113	768	751	751
Number of Assay Values Trace	113	112	91	751	714	219
Maximum	9.00	2.380	0.0950	7.830	2.200	0.2720
Minimum	0.19	0.000	0.0000	0.000	0.000	0.0000
Range	8.81	2.380	0.0950	7.83	2.200	0.2720
Total	124.12	39.77	1.1860	394.35	137.851	1.9660
Mean	1.0984	0.3519	0.0105	0.5135	0.1836	0.0026
Variance	0.8977	0.1321	0.0001999	0.4965	0.07375	0.0001605
Standard Deviation	0.9475	0.3634	0.01414	0.7046	0.2716	0.01267
Geometric Mean	0.9109	0.2356	0.0092	0.2413	0.1008	0.0046

ACKNOWLEDGMENTS

The author would like to thank specific individuals whose background and experience in the district have contributed significantly to the current knowledge about the Bornite breccia pipe. Jim Matlock collared the discovery hole, drill hole CC-2, in 1976, and his recollections of the experience and methodology leading to the discovery were very helpful. Jim Garmoe was a personal mentor early in this author's career and was responsible for the Kinross (Plexus at the time) view that the deposit was a volcanic breccia pipe similar to Los Pilares in Mexico—a deposit on which he had done extensive work years ago. Greg Gosson and Stan Dodd were Plexus geologists who established much of the framework from which

current ore reserve estimates and geologic models have been built. Cyrus Field and his students at Oregon State University have contributed geologic input into the economic geology of the Bornite pipe. Cy Field's personal enthusiasm has been a constant encouragement. Michael Cummings and his students at Portland State University have contributed much to unraveling the complex volcanic geology of the Western Cascades and the area immediately to the east of the Bornite pipe. Mike Cumming's discussions on the deposit have helped in the science and public-relations issues we have dealt with over the past few years. My thanks also go to Frank Hladky of the Oregon Department of Geology and Mineral Industries for encouraging the publication of our scientific work and, once again, Mike Cummings and Cy Field for reviewing this paper.

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No Name Caves in southwestern Oregon are now under BLM care

by Kathleen Murphy, Oregon Department of Geology and Mineral Industries, Grants Pass field office, with photos by John Dutcher, U.S. Bureau of Land Management, Medford, Oregon

The U.S. Bureau of Land Management (BLM) recently traded 41 acres of timber land to Brazier Forest Industries in exchange for 758 acres of Brazier property in southwestern Oregon, thus acquiring several caves that BLM plans to make accessible and enjoyable for the general public. Most noteworthy among these caves are the two caves this author visited, No Name Cave and Lake Cave (often together called the No Name Caves), of which No Name Cave is considered the second longest limestone cave in Oregon—after Oregon Cave in the Oregon Caves National Monument.

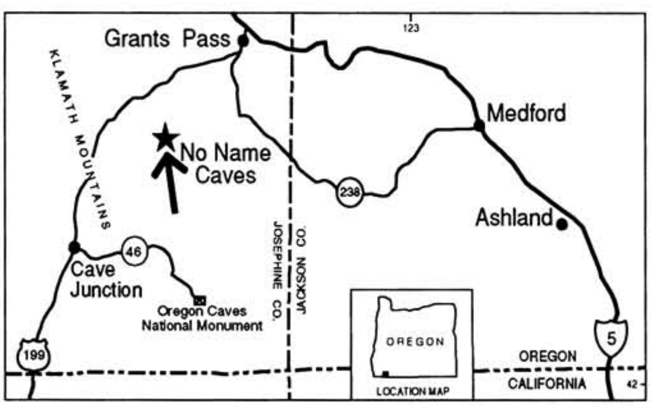

Figure 1. Location of No Name Caves (arrow).

The caves have been known for some time but were accessible without control and have suffered from vandalism and illegal garbage dumping. BLM will include the caves in its ecosystem management plans to protect the uniqueness of the caves and possibly existing bat colonies or other wildlife in them, while making the area available for public enjoyment. Long-range plans may include a picnic area, signs with maps, a day-use parking area, a lookout tower, trails to the caves, and perhaps guided tours. Natural Resource Specialist John Dutcher of the BLM Medford office was kind enough to offer himself as guide for a tour of the caves.

Located in the mountains near Grants Pass (Figure 1), the caves are nestled in the forest, with beautiful meadows nearby. Geologically, much of this part of southwestern Oregon is made up of mainly sedimentary rocks that are known as the Applegate Formation and contain extensive lenses (an area totaling 4,000–5,000 acres) of limestone. Erosion of the limestone has produced the many caves in this area and the wonders inside them.

The two caves are on a south-facing slope (Figure 2). The upper (No Name) cave contains a well-decorated series of large chambers; the lower (Lake) cave is quite a bit smaller, somewhat barren of formations, and subject to flooding. Total distance between the two cave entrances is about 750 ft. The year-round temperature inside the caves is about 40°F, not affected by any wind. Colors seen in the caves are red, white, black, chocolate brown, and orange. Although

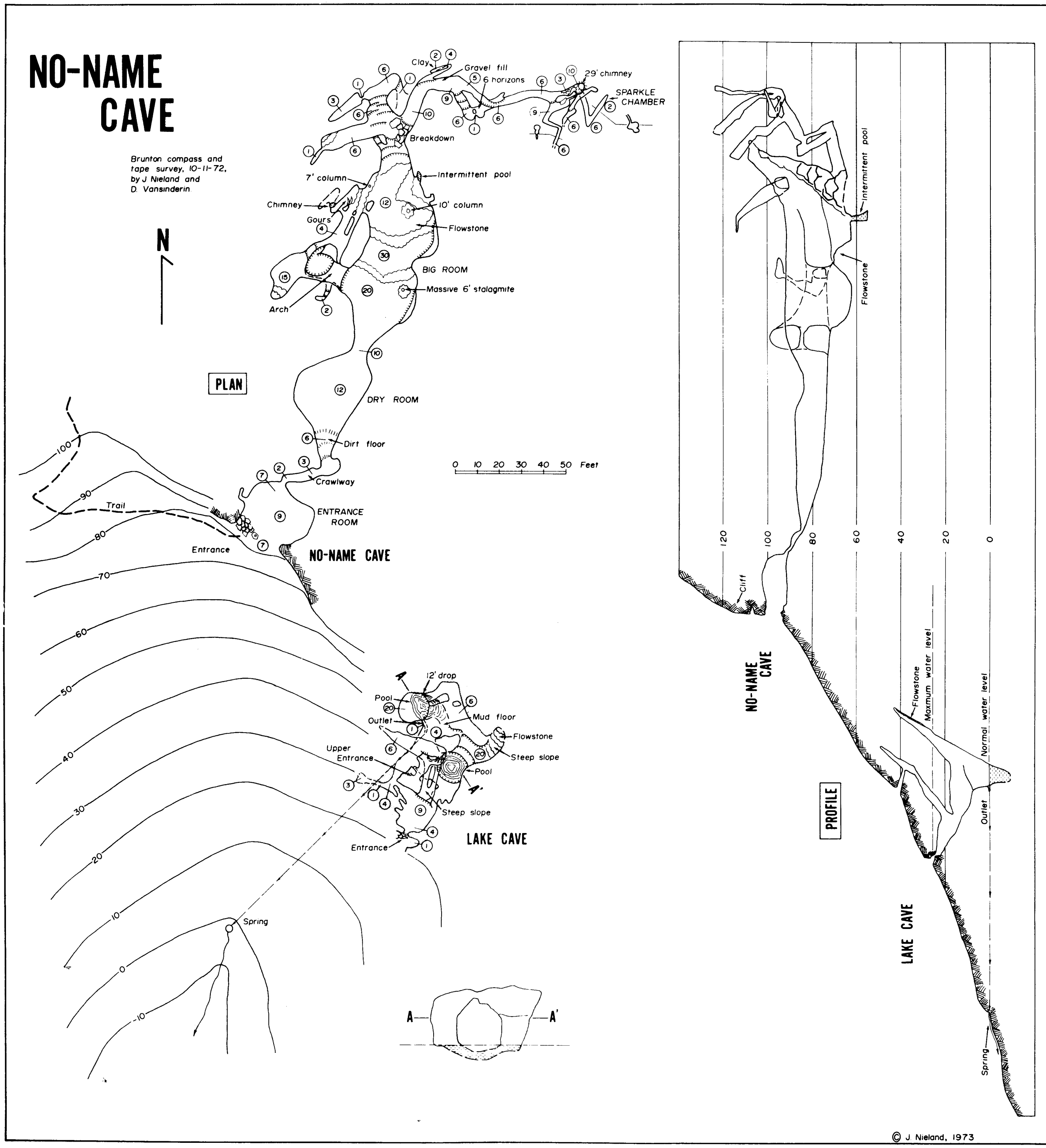

Figure 2. Maps of No Name Caves in plan view and profile, drawn by J. Nieland. Reproduced, with permission, from "Caves of Oregon," Bulletin 4 of the Oregon Speleological Survey, copyright 1975 by Charlie and Jo Larson, Vancouver, Washington. Originally prepared for use by the Audio-Visual Aids Committee of the National Speleological Society. Circled numbers of plan view are ceiling heights in feet.

we did not see much water, we could hear dripping. We did not see any animals in the caves. It was sad to see that quite a bit of vandalism has damaged the caves, and we saw one large trash bag full of litter being carried out.

To enter No Name Cave (Figure 3), you must crawl about 50 ft through a 3-ft-diameter tunnel that slopes downward. You end up in a large chamber, where it is possible to stand up. I was struck by the utter quietness and the still air. Once inside the cave, we did not see any sources of light except where we had come in, which led us to believe that only this one entrance exists. We traveled approximately 220 ft back into the large cave and went into several chambers, which required a moderate amount of climbing and squeezing through narrow openings. At first, I found it very hard to overcome my fear of entering underground confined places, but once I was inside and found everything so different and beautiful and fascinating, I found it just as easy to lose and forget that fear.

Figure 3. Entrance to No Name Cave.

Figure 5. Closeup of formations such as shown in Figure 4.

Being in a cave is like being in a different world, with colorful, unfamiliar forms everywhere around. Specific names have been given to many of these forms created by the movement of mineral-laden water: We saw "flowstone," a coating on the floor or the walls that consists of a sheet of calcium carbonate deposited by slowly flowing water. As it accumulates, it assumes forms that closely resemble masses of ice or large, impressive cascades in stone. "Rimstone pools" are basins with a rim built up of calcite precipitated from slowly overflowing water. "Bacon-rind drapery" is a type of "dripstone" (Figure 4) that projects from the cave wall and ceiling in thin, translucent sheets, sometimes with parallel colored bands. In some places, several rows of such draperies were hanging from the ceiling, and they looked like huge tobacco leaves lined up (Figure 5). "Soda straws" are hollow, tubular "stalactites" (mineral forms like icicles hanging from the ceiling). "Stalagmites" are conical mineral deposits growing upward from the floor through the action of the dripping water. One of these was so huge that it reminded me of Jaba the Hut, a character in *Star Wars*.

The cave also contained columns (Figure 6), which are formed by the union of a stalactite with its complementary stalagmite. One such column was 30 ft high and 2 ft in diameter. We encountered white gypsum as a crust on the rock surface. "Grape" formations in the caves are clusters of smooth, nodular, microcrystalline calcite; each cluster has a lumpy surface, resembling a bunch of grapes. We also saw "scallops" that consist of mosaics of small, shallow, intersecting hollows formed on the surface of soluble rock by turbulent dissolution (i.e., uneven dissolution caused by moving water). These hollows are steeper on the upstream side; the smaller ones were formed by faster flowing water. "Pendants," closely spaced groups of solutional remnants, were hanging from the ceiling.

Lake Cave (Figure) was easier to enter, and we were able to walk in. Almost as soon as we had entered, we came to a hole that went down about 40 ft into a chamber apparently about 20 ft across. We were not equipped with climbing gear, so we did not venture down but began to look around. Because it was slippery, we had to step carefully so as not to fall down the deep hole. We climbed up on a ledge and saw small openings too difficult to enter. This cave was not as colorful and did not have as many interesting formations as the large No Name Cave.

Visiting caves is a beautiful experience but also a dangerous one if you do it unprepared. Some tips for going into caves:

- Never go into a cave alone, and always stay with your group.
- Never go without letting someone know where you are going and when and where you expect to return.
- Step carefully and cautiously, and be prepared to get very dirty.
- Take plenty of lights (my flashlight went out after two hours). Carry three separate light sources, all with fresh batteries.
- Wear a hat; knee pads are helpful when you crawl; gloves can protect your hands from sharp rocks; and hiking boots give sure footing on slippery surfaces.
- For the No Name Caves, make sure you have current information about access. Some trails may lead you to private land and locked gates.

For information about the No Name Caves contact John Dutcher, U.S. Bureau of Land Management, 3040 Biddle Road, Medford, OR 97504, phone (503) 770-2277. □

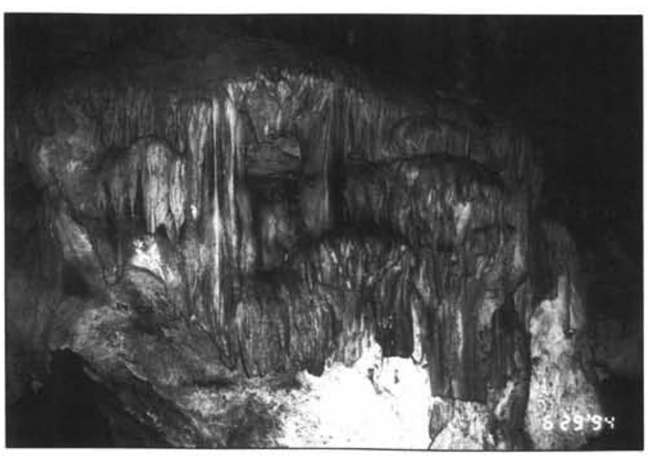

Figure 4. Dripstone with draperylike features.

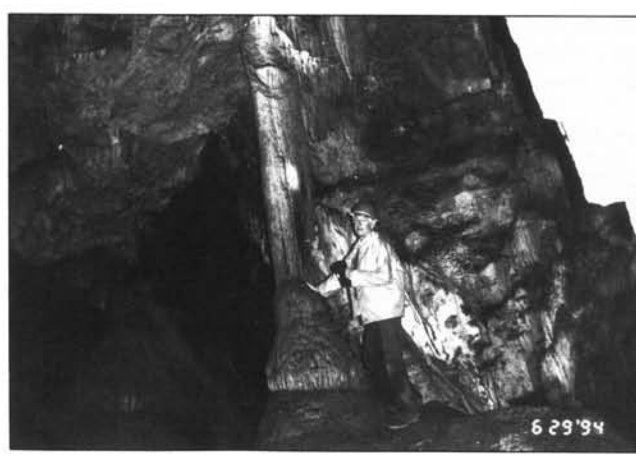

Figure 6. Column formed when stalactite and stalagmite meet.

Loma Prieta damage largely attributed to enhanced ground shaking[1]

by Thomas L. Holzer, U.S. Geological Survey, 345 Middlefield Road, MS 977, Menlo Park, California 94025-3591

INTRODUCTION

Earthquake hazards are commonly treated independently by Earth scientists, yet when a large earthquake occurs, property losses are seldom totaled separately for each earthquake hazard. Four years after the 1989 Loma Prieta earthquake rolled through northern California, a quantitative answer to the following question is not yet available: How much damage was caused by ground shaking, liquefaction, landslides, tectonic ground rupture, or tsunami?

Although the consequences of one earthquake do not necessarily follow for others, an answer to this question will help guide public policy and set research priorities. The cost effectiveness of earthquake hazard mitigation can be improved when the relative significance of earthquake hazards is known, because it enables public agencies to concentrate mitigation efforts on the most portentous hazards.

An answer also encourages cost-effective, problem-focused research by providing a rational basis for allocating research dollars. This is particularly timely because congressional reauthorization of the National Earthquake Hazards Reduction Program is currently under debate. A congressionally mandated review of the program criticized its lack of coordinated programmatic strategic planning, which would direct its resources into efforts that are priority-ranked and problem-focused. The program review also emphasized a need for greater incentives to implement earthquake risk reduction measures. Identifying the relative importance of earthquake hazards helps set priorities for both problem-focused research and implementation.

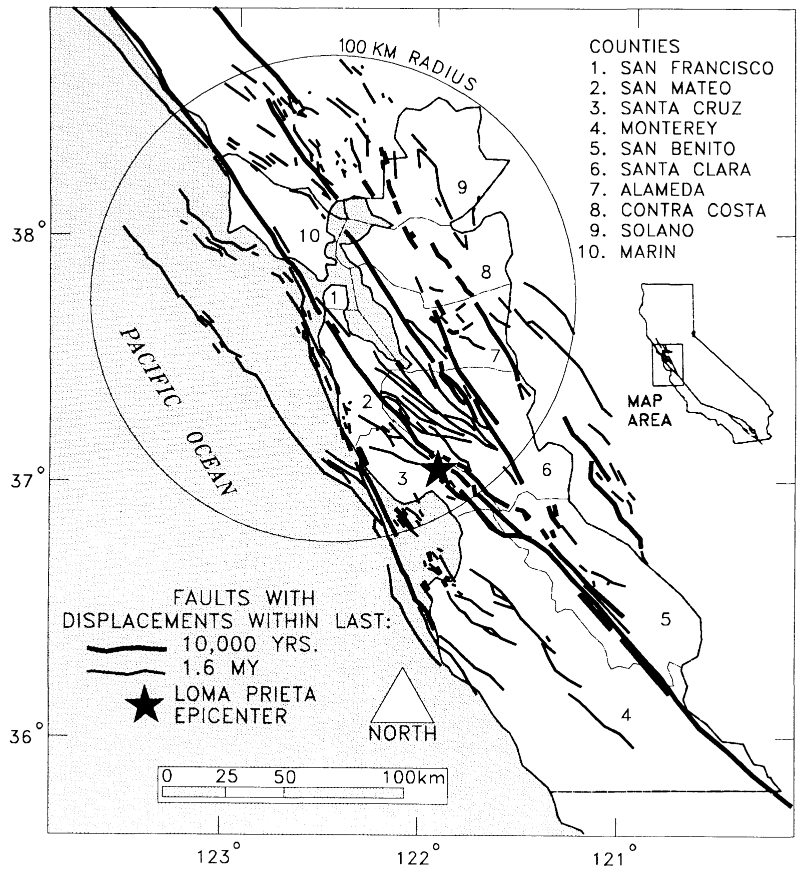

Figure 1. Map of counties that suffered property damage from the Loma Prieta earthquake and faults that offset Holocene and Quaternary sediments. The 100-km (62-mi) circle encompasses the region in which magnitude 7 earthquakes might cause significant damage to parts of the San Francisco city and county that are prone to enhanced ground shaking.

THE 1989 LOMA PRIETA EARTHQUAKE

The moment magnitude 6.9 Loma Prieta earthquake, which hit at 5:04 p.m. PDT on October 17, 1989, was the largest earthquake to shake the San Francisco and Monterey Bay areas since the great San Francisco earthquake of 1906 (Figure 1).

Ground shaking from the earthquake was felt over an area of more than 1,000,000 km^2, and damaging ground motions were observed at epicentral distances of approximately 100 km along selected azimuths (Plafker and Galloway, 1989). Damaging liquefaction and landsliding were triggered at similar epicentral distances. Large ground cracks—not related to shallow downslope movements—occurred in the epicentral region and damaged houses, roads, and underground utilities. In addition, a small but nondamaging tsunami was observed at Moss Landing on Monterey Bay.

The earthquake caused 63 fatalities and 3,757 injuries (McNutt, 1990). At least 12,000 people were displaced from their homes. Physical losses included damage to 23,408 private homes and the destruction of 1,018. In addition, 3,530 commercial buildings were damaged, and 366 were destroyed. Three bridges suffered collapses of one or more spans, and major port and airport facilities experienced significant damage. Electrical service was interrupted to approximately 1.4 million customers, and normal gas service was interrupted to 150,000 customers, about 90 percent of whom turned off their gas supply after the earthquake.

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COST OF THE EARTHQUAKE

The California State Office of Emergency Services (OES) estimated that the losses associated with direct property damage and disrupted transportation, communications, and utilities totaled $5.9 billion (Table 1). These approximated losses were compiled from surveys by local and county governments, state agencies, and the Red Cross. The OES figure is the only systematically compiled estimate of total damage caused by the Loma Prieta earthquake. Approximately $4 billion of the damage was to private homes and commercial and public buildings, and $1.8 billion was to transportation facilities and utilities (McNutt, 1990). Approximately $100 million in damage was unclassified.

A precise and independent loss compilation is beyond the scope of this study and is not attempted here. Such a compilation is difficult because not all damage was reported and because post-earthquake repairs commonly are not just restorations to pre-earthquake conditions but include structural upgrades if not outright replacement. A minimum estimate that provides some confidence in the OES estimate can be made by summing federal, state, and private insurance expenditures (Table 2). Expenditures compiled in the table probably underestimate the total cost of Loma Prieta because nonreimbursed losses were omitted. For example, residential losses are not included

Table 1. *Loma Prieta earthquake losses by county*

County	Distance from earthquake (km)	Total damages (million $)
Alameda	48–100	1,472
Contra Costa	74–118	25
Marin	100–168	2
Monterey	19–203	118
San Benito	27–139	102
San Francisco	85–108	2,759
San Mateo	30–90	294
Santa Clara	7–60	728
Santa Cruz	0–41	433
Solano	107–165	4
	Total	5,936

if they were not covered by insurance; only about 32 percent of homeowners purchase earthquake insurance in the area affected by Loma Prieta (Roth and others, 1992).

LOSSES CAUSED BY EARTHQUAKE HAZARDS

To estimate the loss from each earthquake hazard during Loma Prieta, I compiled property losses that were directly attributable to liquefaction, landslides, ground ruptures, and tsunamis and then assumed that the remaining damage—the difference between the total OES loss estimate (Table 1) and the aggregate loss for these hazards—was caused directly by ground shaking. Losses caused directly by ground shaking were then subdivided into those caused by either normally attenuated or enhanced—that is, higher than expected—ground shaking.

To subdivide direct shaking losses, I used a threshold distance from the earthquake at which ground shaking typically associated with a magnitude 6.9 earthquake would not be expected to cause significant damage even to structures with low seismic resistance. I then compared the distance of each county from the earthquake (Table 1) to this distance. For counties that spanned the threshold distance, I assigned all of the loss in the county to normally attenuated ground shaking. The small size of most counties made it easy to subdivide the shaking losses (Figure 1).

This method for assigning losses to specific hazards provides only crude results, but it is adequate for establishing the thesis of this study. It works for the Loma Prieta earthquake because the losses

Table 2. *Expenditures by government agencies and private insurance*

Agency	Expenditure (million $)
Federal Emergency Management Agency	643
Federal Highway Administration	774
Small Business Administration	582
Other federal agencies	286
CALTRANS	1,500
Other California state agencies	1,224
Private insurers	902
Total	5,911

and their uncertainties—from permanent ground deformation were modest, as were indirect losses, such as those due to fire. It also circumvents two onerous tasks: sorting through tens of thousands of claims and building permits and trying to distinguish between repairs and upgrades, and estimating the characteristics of ground shaking at each damage site.

A threshold distance of 26 miles was used to distinguish between damage caused by normally attenuated and enhanced ground shaking. This corresponds to the distance at which ground-motion attenuation relationships for a magnitude (M) 6.9 earthquake (Boore and others, 1993) predict that peak ground acceleration on firm ground would have decayed to a non-damaging level of 0.10 g. This distance is consistent with correlations of size of area shaken at modified Mercalli intensity 7, the intensity at which damage to poorly built structures is considerable, with earthquake magnitude. Such correlations yield an equivalent radius of 31 miles for M=6.9 (Hanks and Johnston, 1992).

D.K. Keefer, D.J. Ponti, and I—the editors of U.S. Geological Survey Loma Prieta earthquake Professional Paper chapters on permanent ground deformation—compiled the estimates of losses caused by landslides, ground rupture, and liquefaction (Table 3). We did this primarily by contacting engineers and public officials responsible for repair activities at sites with damage. The total loss from these causes is probably accurate to within 50 percent.

Property losses from each earthquake hazard are summarized in Table 3 both as dollar losses and percentages of the total loss. Ground shaking is clearly the primary cause of damage. Ninety-eight percent, $5.8 billion, of the property losses was directly from shaking. Table 3 also reveals that approximately 70 percent of the property losses from Loma Prieta were caused by enhanced ground shaking. Although locally devastating, only 2 percent, $131 million, of the property damage was attributed to liquefaction, landslides, and tectonic ground rupture.

Although this approach does not identify the specific causes of enhanced ground shaking during the Loma Prieta earthquake, many investigators have concluded that the primary cause was local amplification by Holocene clayey-silt deposits that were deposited in San Francisco Bay (Borcherdt and Glassmoyer, 1992). Other potential causes of elevated incoming bedrock motions included a critical reflection off the base of the crust (Sommerville and Yoshimura, 1990) and directivity (Campbell, 1991), a phenomenon by which amplitudes of seismic waves are higher in the direction of the rupture.

IMPLICATIONS

Ground shaking as the primary direct cause of earthquake damage has been assumed for years; the importance of enhanced ground shaking as a hazard, however, is not as widely appreciated. Thus the degree to which the significance of enhanced ground shaking can be projected from the Loma Prieta earthquake to future earthquakes elsewhere in the United States is a critical consideration, if this aspect of Loma Prieta is to have broad application.

Table 3. *Loma Prieta earthquake losses by earthquake hazard*

Earthquake hazard	Total damages (million $)	Loss (% of total)
Ground shaking		
Normally attenuated	1,635	28
Enhanced	4,170	70
Liquefaction	97	1.5
Landslides	30	0.5
Ground rupture	4	0
Tsunami	0	0
Total	5,936	100

Clearly, one must be cautious when drawing conclusions from a single earthquake, but two considerations suggest a basis for concern. First, many American cities were founded adjacent to water bodies, and hence their oldest facilities tend to be in areas underlain by geologically young floodplain, estuarine, and lacustrine sediment, all of which have potential for amplifying earthquake shaking. Thus, although the degree of hazard may vary among urban areas, the potential for enhanced shaking is present to some degree in many urban areas. Second, the next most damaging earthquake in North America in the 1980s was the 1985 Michoacan earthquake; although it was 217.5 miles from Mexico City, it caused approximately $4 billion in property loss there because of enhanced ground shaking (Anderson and others, 1986).

Research into enhanced ground shaking and its effects on manmade facilities as well as mapping of urban areas susceptible to enhanced shaking would improve any hazard mitigation effort, from insurance programs to mandatory construction requirements. Soil linearity—the extent to which soft-soil amplification factors can be extrapolated from low to high levels of shaking—remains a controversial subject. Some investigators even predict that ground shaking will be reduced in areas underlain by soft soils when large earthquakes occur nearby (Idriss, 1990). Despite the availability of several methods for mapping enhanced ground shaking, no specific method has been widely adopted and applied. To further compound the problem, even when ground shaking values are known, techniques for estimating building damage in earthquakes are approximate (Housner, 1989).

Susceptibility to enhanced ground shaking is relevant to setting priorities for mitigation through seismic zoning—classification of land based on its earthquake hazard potential. For example, following the Loma Prieta earthquake, California enacted legislation, the Seismic Hazard Mapping Act of 1990, which requires the state geologist to prepare maps of areas susceptible to earthquake hazards—strong ground shaking, liquefaction, and landslides. Mapping of potentially active tectonic ground rupture was already required by the Alquist-Priolo Special Studies Zone Act of 1972. Equal emphasis on earthquake hazards—ground shaking, liquefaction, landsliding, ground rupture, and tsunami—is not the lesson of Loma Prieta. The relative significance of earthquake hazards must first be assessed, because some may be more significant than others.

Potential for enhanced ground shaking also has implications for estimating the seismic risk to many existing and particularly older facilities that are underlain by soft soils in both the San Francisco Bay area and other urban areas. Many of these facilities, which have low seismic resistance, may be at significant risk from magnitude 7 earthquakes within a 62 mile radius, not just from local events.

For larger earthquakes, the radius becomes even larger, which requires earthquake potential to be assessed over broad areas around urban centers. This pertains not only to California, where many large earthquakes have occurred on seismogenic geologic structures well removed from California's primary seismogenic zone—the San Andreas fault—but to the remainder of the United States as well. The problem is illustrated for San Francisco in Figure 1, which reveals the large number of potential seismogenic faults exposed at the surface within 62 miles of the city.

As the 1994 Northridge, California, earthquake forcefully demonstrated, assessment of earthquake potential immediately within an urban area remains necessary. Seismic design of new facilities is largely driven by nearby seismogenic geologic structures, because they are believed to produce the largest ground motions. However, earthquake hazard reduction in urban areas must address all existing facilities, and the risk to older facilities is increased when the more distant seismogenic geologic structures are included. This is an important, albeit not a new, lesson from the Loma Prieta earthquake. By focusing only on nearby seismogenic geologic structures, the risk in urban areas due to enhanced ground shaking is underestimated.

CONCLUSIONS

Approximately 98 percent of the $5.9 billion in property damage from the 1989 Loma Prieta earthquake was caused directly by ground shaking; enhanced ground shaking was directly responsible for approximately two-thirds, $4.1 billion, of the total property loss. Permanent ground deformation accounted for only about 2 percent of the damage.

These observations indicate that we must understand local controls of shaking and enhancement, not just local sources of shaking. Earthquake hazard reduction efforts in the United States would benefit from improved understanding of phenomena that enhance ground shaking, including seismic wave amplification in soft soils at high levels of shaking; mapping areas susceptible to enhanced ground shaking; and delineating seismogenic geologic structures at greater distances from urban areas with soft-soil conditions.

ACKNOWLEDGMENTS

I am grateful to R. Bernknopf, R. Brown, T. Hanks, W. Joyner, C. Mortensen, and particularly R. Page for thoughtful and constructive reviews of early drafts of this manuscript. J. Buika, A. Goldschmidt, J. Gates, D. Keefer, D. Ponti, and J. Regala helped collect loss information. J. Regala helped clarify the methodology.

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A guide for evaluating mineral ventures — 1: Business issues

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INTRODUCTION

Mineral ventures can be very profitable, but they are also financially risky. Individuals should carefully evaluate mining and oil and gas deals before investing in them. While there are many successful ventures, there are also many failures and even some fraudulent schemes. Investors must do their homework.

This is the first of two articles giving you tips on how to investigate mineral ventures. In this article, we will look at business issues. It will help you decide whether a mineral project is an appropriate investment for you. It also points out some things to look out for and where to get help.

The second article, which will be published in a later edition of *Oregon Geology*, explains how you can physically evaluate a mineral deposit. This is a crucial step. It tells you if the property is worth risking your money. The article will also cover some of the legal steps needed before opening a mine or drilling a well. Mineral extraction is carefully regulated, so it is important that you understand the basic rules and laws.

Be aware that we cannot include everything you need to know. If you are thinking about investing, hire qualified scientific, legal, and financial advisors. Even if you have expertise in one of these areas, it is still worth getting a second opinion. A few hours of an expert's time should not cost much and can be well worth the cost.

See cover photo and cover photo caption. The Comer Mines Company apparently tried to revive the Present Need Mine near the confluence of Comer and Dixie Creeks northeast of John Day in Grant County. No mining activity was reported for the period during which the company was in existence.

BUSINESS ISSUES

Anytime people try to sell an investment to the public, they must offer a prospectus. A prospectus is a written report that discloses all of the important facts about an investment. For mineral projects, this includes geological data, cost estimates, a market analysis, and a discussion about competitors. A prospectus will also tell you about the qualifications and history of the company. It provides the same information about the venture's principals (officers, key employees, and major investors). After reading a prospectus, average investors will know what will be done with their money and what the risks are. That is why you should always carefully review a prospectus before sending in any money.

In Oregon, investments are registered with the state's Corporate Securities Section. It is a part of the Department of Consumer and Business Services. Any investment sold in Oregon must be registered with the state, even if the business is located somewhere else.

A few investments are exempt from the registration requirement, for example, businesses financed entirely within a family. Even in such a case, however, any business seeking investment dollars must make full and truthful disclosures, i.e., the investors must all be fully informed about the risks and plans for the business. Failure to provide such information opens the door to fraud charges.

If those who ask you to invest say that they do not have to file a prospectus, call the Corporate Securities Section in Salem at (503) 378-4387. The Corporate Securities people will direct you to the right person in state government who can tell you if an investment is exempt from the rules. If it is, ask the seller for a copy of the venture's business plan or any other written materials that show what your money will be used for and what the risks are.

If you invest, keep the prospectus, business plans, and other documents in a safe place. If it turns out that you were misled, these documents may serve as evidence in case you need to sue. If you can prove fraud, however, you still have major hurdles to overcome. Recovering your investment is often difficult and sometimes impossible. People who commit securities fraud may disappear after they have your money. At other times, they will spend the money and leave you with nothing to collect. That is why you should thoroughly investigate a venture **before** you hand over your money, not after.

Once you have the prospectus or business plan, verify all of the key statements. Factual information is the easiest to check, but many claims are opinions. Having a very optimistic opinion is, while misleading, not fraudulent behavior. You have to assess the realism of the prospectus and business plan. For that, you have to do research.

Read and understand the investment documents. Your attorney, accountant, and technical advisors can give you a good sense of the risks you are taking.

All mineral ventures are a gamble. The "Risk Factors" section of the prospectus outlines some of the dangers. Even good projects can fail for unforeseen reasons. You may lose all your money. Should your investment succeed, you may have trouble selling your interest in it. This is called illiquidity. It is a common problem especially for people who need to take their money out on short notice. For these reasons, never risk retirement funds, money set aside for important purchases, or cash you might need for living expenses. You should never invest more money than you can afford to lose.

MARKET FORECASTS

Crucial to any prospectus or business plan is its market forecast. Pay close attention to the forecast. It is the basis for all the revenue and profit projections.

A market forecast is an opinion. Those wanting you to invest in their venture will make their business look as good as possible. They may be too optimistic about the market. It is up to you to make sure the forecast is reasonable.

Assuming that mineral prices will rise faster than the rate of inflation is a common planning mistake. Over the long run, such price increases rarely happen. Competition keeps most metal and mineral prices lagging behind the inflation rate. Businesses are always looking for ways to produce more goods at lower cost. In mining, these productivity gains can average one percent a year. If that happens to the mineral you are producing, you should expect prices to lag one percent behind the annual inflation rate. Over several years, this gap can have a dramatic effect on your venture's profits.

Be suspicious of any prospectus or business plan based on sharply higher prices. Unless there is a clear economic reason for it, you should lower the forecast. Bear in mind that rising demand for a mineral is not necessarily an economic reason for expecting higher prices. Higher demand, in fact, often leads to lower prices, because it allows mines to operate at higher, more efficient rates. One simple test you can perform on a plan is to simply replace the high price forecast with current prices. What does this do to the project's profits?

Sometimes forecasting higher prices makes sense. Metal and energy markets are cyclical. There are times when prices are unreasonably high or low. Shortages can drive prices so high that even the least efficient mines make extraordinary profits. At times of poor demand and oversupply, the best-run mines can lose money. These are both temporary conditions. Economic forces eventually force prices to levels where industry profits are normal. This is called the long-run sustainable level. A good forecast uses it and then factors in the industry's productivity. Productivity changes directly influence the long-run price level.

Usually, productivity improves over time. Declining productivity, however, does occur. This happens when laws are passed that raise costs. If the impact is large and felt by many producers, productivity will fall. Competitive forces will cause prices to rise faster than inflation.

Is the basis for the price forecast correct? Too often, people use published prices to estimate revenues. It is common, however, for a project's realized price to be less than published figures. A small difference in quality can cause a big price variance. So can shipping costs. Make sure the quality and location of your project's output fits the commercial standard used for the published price.

The other side of the revenue equation is sales volume. If the mining venture produces an unusual mineral, market size becomes a limiting factor. This is also true for bulky, low-value products like crushed rock, clay, and sand. An accurate local market demand forecast is important in these cases. You can sell only so much material in a limited market before you start pushing prices down. Be sure that the market can comfortably absorb the new supply coming from your venture. If you are exploring for oil or natural gas, think about how you are going to send them out to markets.

PRODUCTION COSTS

A prospectus has cost estimates. If it is an exploration project, costs should be well defined. Any figures for ultimate production are speculative and should be viewed as such. Production cost estimates for known mineral deposits will be rooted in more solid assumptions. Check these assumptions for their realism.

You should compare projected costs with those of other similar properties. This can be difficult, but it is an important step. The U.S. Bureau of Mines is a good place to start. The Bureau has specialists in every mineral commodity. Its publications *Minerals Yearbook* and *Mineral Facts and Problems* both list the names of specialists and contain excellent market summaries on different minerals. You can find these books in most public libraries.These publications, however, are slated for termination due to federal budget cuts.

When comparing costs, consider the operating conditions. Is the mining method of your project inherently more or less expensive than that of its competitors? Are the mining or drilling conditions harder or easier? Does the geology make it expensive to extract the product from the ground? Are you in an area where roads, utilities, and labor are freely available? Does your property have special environmental risks?

Your objective in examining production-cost figures is to assure yourself of the venture's plausibility. If the prospectus or business plan contains low cost numbers, be ready to ask questions. Many mineral ventures fail because the owners underestimated their costs. The opposite also occurs. You could be given excessive cost estimates. In this case the promoter is hoping you are not going to check the figures. That way, the promoter can collect far more cash than is actually needed to fulfill the business obligation discussed in the prospectus. The promoter and other insiders can then take the remaining money for themselves.

SOURCES OF INDUSTRY INFORMATION

Many useful publications can be found in the library of the Department of Geology and Mineral Industries, which is open to the public. We also have publications and maps for sale through our Nature of Oregon Information Center. It is an excellent place to start your research. The center is on the first floor of the State Office Building in Portland. Some library resources and for-sale materials are also available at our field offices in Baker City and Grants Pass. See page 98 of this issue for addresses.

If your project involves coal, oil, natural gas, or geothermal energy, contact the U.S. Department of Energy for help. If it involves fertilizer minerals, such as phosphates, the U.S. Department of Agriculture has experts available. Their help, like that of the Bureau of Mines, is free.

Do not overlook annual reports, magazines, and newspaper articles. They often report costs. You can also learn about other issues affecting the industry. Ask your librarian for help in researching publications.

Most other data sources cost money. There are consultants who specialize in various minerals. You can get their names by contacting some of the larger producers. Depending on the size of your investment, it may be worth paying a consultant to spend a few hours reviewing the prospectus for you. A typical industry consultant charges $75 to $150 an hour.

Another source is Dun and Bradstreet. They will send you a report on a company for $75. Reports contain the company's history and background, payment record, biographies of the principals, and reports on lawsuits, liens, and judgments. Sometimes these reports can be used to estimate competitor costs. The phone number for Dun and Bradstreet is (800) 362-2255. When you order a report, be sure to ask if it has the information you are most interested in.

CREDENTIALS CHECK

It is surprising how often people invest their money in projects without first checking the credentials of the principals. Sometimes they skip this step because the person soliciting money from them seems honest. Perhaps the solicitant is complimentary or gives an impressive story about the experience of the enterprise. While all this may reassure you, remember that deceitful people will try to appear honest.

It is up to you to check the backgrounds of the people who want you to invest in their mineral venture. Ask them questions about their past. Ask for their resumes. Do not be afraid of offending anyone. If they are experienced business people, they will expect you to check their backgrounds. If you do not, it could signal that you are a naive investor.

You can hire a private investigator to research individuals. The investigator will call schools and coworkers, conduct computer searches, and get personal credit reports. It typically costs from $100 to $500 for each person you have investigated. The cost varies depending on how much information you need and how complicated the search is. You can save money by supplying the investigator with the person's social security number and date of birth. Computer databases use these, so giving them to the investigator will save money and time.

You have to weigh the costs of doing background checks with the size of your investment. If a private investigator is too expensive, you can do your own research. It will take time, but it will cost you little or no money. The place to start is your library.

A good library has computer databases of newspaper and magazine articles. Bring with you a list of the names and work places of

Reverse side of Comer Mines Company stock certificate shown on front cover. Oregon Historical Society negative number 90671.

the people you are researching. Search the library's databases using these names and places.

Newspaper and magazine articles may give you insights as to whether the individuals actually held the positions they said they did. Pay close attention to stories about unethical business practices. If you find anything that concerns you, copy the article. The news stories often have names of people tied to the person you are investigating. Make a list of them. Don't forget to include the authors of the articles.

If you want to do a very thorough search of newspapers and magazines, try using Nexis. This company has the largest single database of newspaper and magazine articles in the country. The Mead Data Central's Nexis Express will do searches for you. The current charges are $2.50 a page and $6.00 a minute for search time. It is expensive, but very comprehensive. Unlike most literature searching systems, Nexis does a full text search. It will find any mention of the subject in articles rather than just searching for words in headlines and abstracts. The phone number for Nexis is (800) 843-6476. Other companies offering similar services include Dialog, Data Times, and CompuServe.

Use the library to get the phone numbers of schools and businesses cited by the principals. Add these to your list. Put down their graduation and employment dates. Ask the librarian for trade and professional association directories. Get the numbers of associations to which the principals belong.

Your next step is calling everyone on your list. Ask the people you call about the individuals you are investigating. For legal reasons, if there is a serious flaw in a person's background, people may be unwilling to say anything negative. Listen for positive comments. If you do not hear any, ask if the people would be eager to do business with this individual. Ask if they think the individual is highly qualified to be involved in a mineral venture such as the one you are being offered.

When you call a trade or professional association, ask how long the person you are investigating has been a member. Ask who else in the association has had dealings with the individual. Call that person. Bear in mind that in many cases all it takes to become an association member is to simply pay a fee.

Colleges and universities will verify degrees earned. If the person claims to have done research or a thesis, call the department he or she worked in and ask some questions.

The human resources departments of most companies will verify employment. They can tell you when the person worked there and what her or his title was. You can try to talk to the person who now holds that same position and ask about the individual you are investigating. Both schools and companies, however, avoid giving out detailed information, especially if it is negative.

If your investment is in an established company, check for legal problems. Start by contacting the state and federal courthouses where the company has its headquarters. Also, look for discussions of legal disputes in the company's Dun and Bradstreet report. Bear in mind, however, that a legal problem is not necessarily a sign of fraudulent or dishonest behavior.

If any of the principals are lawyers, call the American Bar Association at (312) 988-5319 or the Bar Association of the state where the principal is located. The ABA compiles public discipline records on lawyers. If you are dealing with a stock broker, call the National Association of Securities Dealers at (800) 289-9999 which also maintains disciplinary records. You can verify the history of many businesses by calling the Council of Better Business Bureaus, where records of complaints made against individuals and businesses are kept.

Oregon's Division of Finance and Corporate Securities will check its records on a person or business for you. It will tell you if it knows of any past problems. You should be aware, however, that a clean record is not proof that businesses or individuals are upright. It just means that there are no complaints or investigations filed on them. Still, the Finance and Corporate Securities people are a great help and their service is free.

Another agency offering free help is the state's Justice Department. Its Civil Enforcement Division has a Financial Fraud section. This section can tell you if a person or business has engaged in any dishonest financial practice. If you already have an investment in a business, but you suspect fraudulent accounting, you should call a Financial Fraud investigator at (503) 378-4732.

The state's ability to keep track of deceptive investment and financial schemes depends on public cooperation. If you feel that you were a victim of a fraudulent mineral venture, report it to the Division of Finance and Corporate Securities. Tell the Justice Department as well. People who engage in unethical business practices know that their victims are usually too embarrassed to report their losses to authorities. The state, however, needs your help to fight such criminal behavior.

If Oregon's records on a venture and its principals are clear, you may want to pursue it with other jurisdictions. If you know the principals worked in other states or Canada, call the fraud and securities departments in those places. Phone numbers of state agencies can be obtained from the North American Securities Administrators' Association by calling (202) 737-0900.

Can you prove that the principals own what they say they have? You can check some mineral claims and oil and natural gas leases with the government. If the property is privately held, there may not be any public documents. In these cases, you should ask for a copy of the agreement between the venture and the landholder. Visit the county assessor's office and verify real estate holdings. They can tell you who owns the property and whether any of the buildings are mortgaged. If the principals say they own equipment, check their Dun and Bradstreet report and make sure the equipment is not leased. The Department of Motor Vehicles can help you find out if the business owns its vehicles. All this will help you establish what the venture's assets are. Just because it is using assets you cannot be certain that it owns them. If the venture fails, you may recover money only from assets the venture owns outright.

RED FLAGS

Sometimes, mining and oil well ventures are fraudulent schemes, so you should watch for signs of deceptive business practices. Some of the more common "red flags" are outlined here. Their presence does not necessarily mean a project is bad, but it should make you ask tough questions.

Does the project involve an esoteric mineral or process? Some schemes feature these because that makes it hard for investors to evaluate the projects. With few outside sources of technical advice, investors tend to depend on the principals for information. This makes it easy for the principals to mislead investors. Even if the project is legitimate, having esoteric features makes it inherently more risky.

If you have trouble researching a mineral or process through the public library, call us at the Department of Geology and Mineral Industries. We can help you. In addition, we usually can give you names of other experts to contact.

Does the prospectus or business plan make a grossly exaggerated claim? For example, one recent project said that a new extraction process would produce over a trillion dollars' worth of gold. Even if it were possible to extract a trillion dollars' worth of gold, it would not be possible to sell it without collapsing the gold market. The entire world market for gold is only about $15 billion a year. In another case, someone had a scheme to extract gold through wells. Anyone knowledgeable about gold mining knows this cannot be done. Investors often fall prey to such extraordinary claims. It happens because they do not use experienced people at such places as the Department of Geology or the U.S. Bureau of Mines.

Does the project rely on the success of a new production technique? Experience shows us that these ventures are extremely risky. Some dishonest schemes pull investors in with exciting stories of a revolutionary technology that will make millions of dollars. If you are faced with such a project make sure the process truly is new and that the venture has the rights to use it. Ask for patent numbers. The U.S. Patent Office will send you copies of patents for $3 a piece. A patent shows its inventor's name. Do your research before investing. Get opinions from knowledgeable people. Consider what they tell you, ask questions, and weigh all the advice before making an investment decision.

Are you being asked to invest over the phone? Often this is a sign of a "boiler room" operation. Boiler rooms are teams of high-pressure salespeople who make unsolicited calls. They are illegal. If someone unexpectedly calls you, do not give any personal information such as date of birth, social security number, or credit card data. If you think it is a boiler room, call the Division of Finance and Corporate Securities or the Financial Fraud Section of the Department of Justice.

Are you being pressured to make a quick decision by people telling you they need your commitment or else you will lose your chance to get in? Fly-by-night schemes use this tactic. They want you to make a rush decision so you do not thoroughly research the deal and back out. They also may be in a hurry to collect money from unwary investors and leave the state. A legitimate business person offering a risky investment wants you to make a careful and informed decision. That way, if the venture does not work out, you cannot go back and claim that you were pressured or deceived.

Are the principals unwilling to give you accurate personal information about themselves? Without it, you cannot authenticate their credit worthiness, experience, and personal reputation. Just as you expect a bank to ask you personal questions when you apply for a mortgage, honest business people expect the same scrutiny from potential investors.

Are you certain the amount of money you are putting into a venture is proportional to your share of the ownership? Some promoters will sell more than 100 percent of a project. While this is illegal, it is also hard to prove.

Another scheme, which has occurred in a few oil well projects, is overestimating exploration costs. The promoters will sell interests in a real oil exploration well. The well might cost $100,000 to drill, but the promoters tell you it should cost $300,000. They then collect $300,000 from investors, drill the well for $100,000 and pocket the remaining $200,000, perhaps as a consulting fee or salary. Sometimes, they may avoid prosecution by fleeing the state. A savvy investor might avoid this by getting expert opinions from industry consultants on whether or not the promoter's cost estimate is fair.

Is there an affinity linking the investors and principals? In some cases, this can be a red flag. An affinity is a common characteristic which ties people together. Examples include a group of war veterans, members of a church, people with common political beliefs, or senior citizens. In several cases in Oregon, dishonest individuals have victimized people by claiming to share a similar background. This is called affinity fraud.

Criminals know that if they sell to one member of a group, it is far easier to sell to others in the group than to outsiders. Compared to strangers, we are simply more likely to believe friends we share interests with and have known for years. This saves the principals both time and marketing expense. That is why groups are so susceptible to fraud. Once it gets a foothold, a fraudulent investment can quickly penetrate an affinity group.

If someone soliciting an investment uses an affiliation as a way to convince you of the validity of a mineral venture, step back and look it over objectively. Try and separate the merits of the venture from other feelings you may have about your group or its individuals.

SUMMARY

Mineral ventures are financially risky. It is up to you to check them out carefully before investing. Be particularly wary of dishonest schemes. Below is a summary of some of the more important actions you should take:

- Get the prospectus and other documents showing where your money will go and what the risks are.
- Ask experts and professionals for their opinions.
- Double-check all material facts by doing research at the library and making phone calls.
- Call the Corporate Securities and Financial Fraud Divisions of state governments in places where the principals had businesses.
- Check the credit and business histories of the venture and its principals.
- Verify any claims of ownership of leases, mineral deposits, or technologies.
- Make sure that the venture has obtained the appropriate permits from government agencies so it can engage in exploration, mining, or drilling.
- Check records of mineral claims, leases, property holdings, and agreements with landholders.

ACKNOWLEDGMENTS

The author gratefully acknowledges the helpful comments and suggestions by reviewers Mike Francis, business columnist for *The Oregonian*, and David Tatman, Chief of Enforcement, Corporate Securities Section, Oregon Department of Consumer and Business Services. □

DOGAMI PUBLICATIONS

Released August 1, 1994:

Digital data and selected texts from *Low-temperature geothermal database for Oregon*, by Gerald L. Black. Released as Open-File Report O–94–9 (one 3½-in. high-density diskette). Price $12.

The inventory of geothermal sites lists 2,193 geothermal wells and springs, more than doubling the number of known geothermal resources in the state over the previous inventory done in 1982. It is part of the nationwide Low-Temperature Geothermal Resource and Technology Transfer Program funded by the U.S. Department of Energy, Geothermal Division, and administered in Oregon by the GeoHeat Center at the Oregon Institute of Technology.

The new geothermal database was produced with the Excel program on the DOS platform. It is divided into three files, one for all the counties of Oregon except the area around Klamath Falls, the second for the Klamath Falls area, and the third for chemical data of all those sites for which such data are available.

Under the title **Low-temperature geothermal database for Oregon**, single paper copies of Black's report have been placed on library open file in the libraries of DOGAMI's offices in Baker City, Grants Pass, and Portland as Open-File Report O–94–8. This paper version contains the databases, the report text with a slightly extended appendix, and five location maps. Availability is restricted to examination in the library. Photocopies can be obtained at cost.

Released August 4, 1994:

Geology and mineral resources map of the Limber Jim Creek quadrangle, Union County, Oregon, by Mark L. Ferns and William H. Taubeneck. Released as map GMS-82. Price $5.

The map covers part of the headwaters of the Grande Ronde River in the southwestern corner of Union County, about 20 mi southwest of La Grande, including a historic mining district and critical salmon spawning habitat. Today, some known deposits of gold and silver still remain, but the general attention is focused on environmental concerns such as landslides and water pollution caused partly by previous mining and road construction. In the most notable case, federal and state agencies are cooperating now under the Oregon Watershed Health Program to reclaim and stabilize the abandoned Camp Carson mine site.

The new map depicts the geology in greater detail than any previous map, including faults and mining sites and prospects. It is accompanied by tables with analytic data and a text discussing rock units, geologic history, mineral resources, and landslides.

Released August 26:

Geology and mineral resources map of the Tumalo Dam quadrangle, Deschutes County, Oregon, by E.M. Taylor and M.L. Ferns. Released as map GMS-81. Price $6.

GMS-81 describes the geology of an area northwest of the city of Bend that is important particularly for the city's water supply. The map identifies twelve rock units, all products of the volcanism that created this region between seven million years and 20,000 years ago, before the glaciers of the last ice age covered and eroded it. It is accompanied by geologic cross sections; brief discussions of the Tumalo fault zone and its earthquake hazard potential, the geologic history, and the mineral and water resources; and tables with analytic data from rock samples.

Geologic map of the Kenyon Mountain quadrangle, Douglas and Coos Counties, Oregon, by G.L. Black. Released as GMS-83. Price $6.

Geologic map of the Mount Gurney quadrangle, Douglas and Coos Counties, Oregon, by T.J. Wiley, G.R. Priest, and G.L. Black. Released as GMS-85. Price $6.

These two quadrangles are situated adjacent to each other about 20 mi west of Roseburg and straddle the border between the two counties. In addition to rock units, both maps show geologic cross sections as well as details of faulting and of landslide deposits.

Mapping of these two quadrangles in the southern Coast Range represents part of DOGAMI's studies of the geology of the Tyee sedimentary basin as well as the wider area around the city of Roseburg. These studies have brought about a considerable amount of new information, which has given geologists a much better understanding of the stratigraphy of the region.

The new maps are all at a scale of 1:24,000 and are produced in two colors—a brown topographic base overlain by black geologic information. They are the results of larger mapping projects in which DOGAMI cooperates with the U.S. Geological Survey in the National Geologic Mapping Program, with other federal, state, and county agencies, and with private industry.

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OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries

VOLUME 56, NUMBER 6 NOVEMBER 1994

IN THIS ISSUE:

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 56, NUMBER 6 NOVEMBER 1994

Published bimonthly in January, March, May, July, September, and November by the Oregon Department of Geology and Mineral Industries. (Volumes 1 through 40 were entitled *The Ore Bin*.)

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, letters, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office (address above).

Cover photo

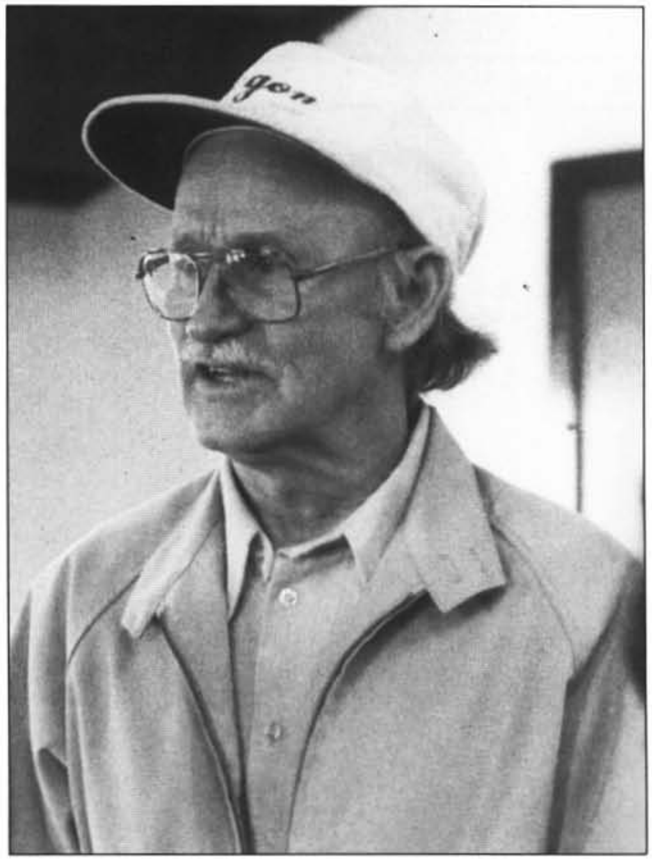
Fort Rock in Lake County, is a spectacular example of the many volcanic features of Oregon that Norm Peterson, whose death we mourn, brought closer to our readers.

Fort Rock is the eroded remnant of a so-called maar, created in early Pleistocene time (about a million years ago) through gigantic steam explosions that occurred when rising magma reached the land surface and encountered large amounts of surface water—a lake, perhaps.

Norm Peterson (with Ed Groh) described such maars in an article in the May 1963 issue of what was then still the *Ore Bin*.

In memoriam: Norm Peterson

Norman V. Peterson, District Geologist for 25 years at the Grants Pass field office of the Oregon Department of Geology and Mineral Industries, died on October 26, 1994, at his home in Grants Pass. It was one day before his 74th birthday.



Norman V. Peterson, during a visit to the DOGAMI field office in Grants Pass in 1990.

Norm retired from his duties in December 1982. During his years with the Department he participated in geologic studies covering most of Oregon and authored or coauthored over 50 articles, papers, and books on both technical and general-interest subjects.

He conducted commodity studies of uranium, limestone, diatomite, pumice, perlite, volcanic cinders, and geothermal resources; worked on numerous county studies including Lake, Klamath, Deschutes, Josephine, and Douglas Counties; assisted with geologic mapping of the Crescent and Jordan Valley 1° by 2° quadrangles; participated in the wilderness mineral evaluations in Harney and Malheur Counties; and helped author nuclear power plant siting and volcanic hazards studies.

He introduced many of our readers to the volcanic wonders of Oregon by his popular articles and field trip guides about such places as Hole-in-the-Ground, Diamond Craters, Cove Palisades State Park, Fort Rock, Newberry volcano, and Crack-in-the-Ground. He was coeditor (with Ed Groh) of the *Lunar Geologic Field Conference Guidebook* (1965), which focused on Oregon's volcanic features at the time when some of them were studied and used as training ground for landing on the Moon.

Beyond his professional accomplishments in his service to the people of Oregon, Norm will be remembered by all who ever met him for his cheerful friendliness. Those who worked with him admired his unflagging willingness to work long hours and endure hardships for the work he loved. □

The geology and mineralization of the President Mine, Bohemia mining district, Lane County, Oregon

by Robert E. Streiff, Geologist, Echo Bay Minerals Company, McCoy Mine, P.O. Box 1658, Battle Mountain, Nevada 89820

ABSTRACT

The geology and mineralization of the President Mine in the Bohemia mining district of Oregon are characteristic of a complex volcanogenic epithermal deposit. Three major phases of faulting and five stages of mineralization have been identified.

Early stages containing quartz with chalcopyrite, galena, sphalerite, and pyrite are typical of the Bohemia district mineralization but do not contain significant gold mineralization. Economic gold mineralization is intimately associated with pyrite in a later dolomite-stibnite and quartz-sulfide event. Vein sediments are associated with the dolomite mineralization. A hiatus in mineralization, followed by renewed right-lateral faulting, separates earlier quartz-sulfide from later dolomite-stibnite mineralization. Postmineral faulting and oxidation have further complicated the deposit.

The gap in mineralization, the radical change in mineralogy, and the anastomosing form of later veining indicate that earlier quartz-sulfide veining represents a deeper epithermal system than later dolomite-stibnite mineralization. This implies rapid erosion of the Bohemia volcanic complex between earlier and later mineralization events.

INTRODUCTION

The President Mine is at the southern edge of the Bohemia mining district, Lane County, Oregon (Figure 1). Although claims are located on several parallel veins, the focus of activity has been on the President or El Capitan vein. The principle workings are on the Coolidge claim, at an elevation of about 1,190 m (3,900 ft). The vein crops out for more than 1,220 m (4,000 ft) on the south-facing slope in the Saint Peter Creek canyon, mainly in sec. 23, T. 23 S., R. 1 E. The canyon is very steep, and outcrops are numerous.

Literature on the President Mine is lacking due to a relatively late development history. Recent mapping, sampling, and development at the mine have afforded the opportunity to study the deposit in some detail.

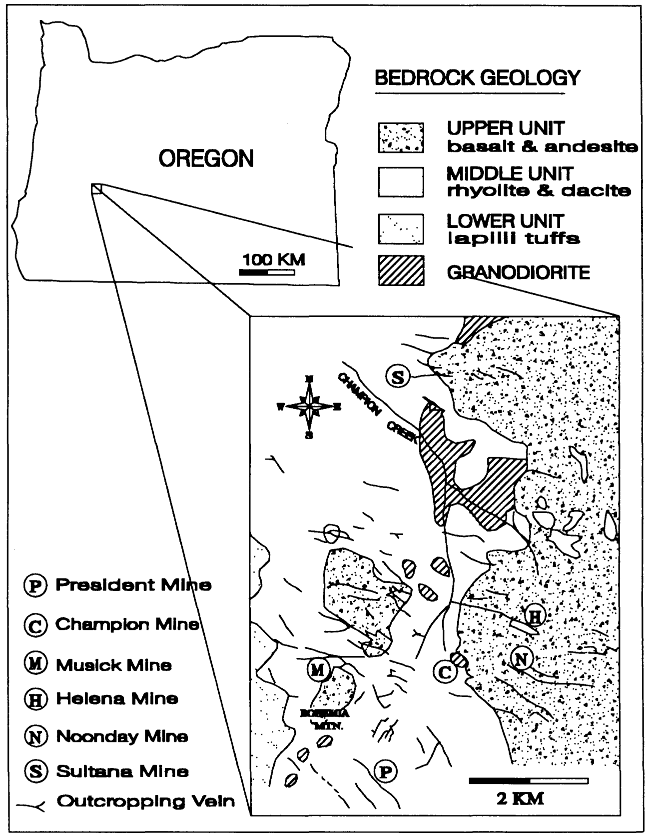


Figure 1. Location map of the Bohemia mining district. Modified from Schieber and Katsura (1986).

HISTORY

The first claims located on the President vein were filed by A.P. Churchill in 1898. Churchill trenched the President and parallel veins, drove several short adits, and attempted to finance development of the claims by issuing stock. Ore was found on the Cleveland claim (later to become the Coolidge claim), but it was not developed by Churchill (W.B. Patten, personal communication, 1979).

The claims were taken over on a labor lien in 1926 by William B. Patten. Patten began developing ore on the Coolidge claim and, by 1940, was operating a two-stamp mill on ore from the upper Coolidge adit, which was by then about 30 m (100 ft) deep. Patten's two-stamp mill was destroyed by an avalanche in 1946. The lower Coolidge adit was driven about 90 m (300 ft) and encountered good ore in the three shoots. Based upon showings observed on the claims, Patten entered into partnership with H.L. Lilegren in 1950 to build a road to the claims. Reconstruction of 4.8 km (3 mi) of road and construction of 9.7 km (6 mi) of new road were accomplished before the partnership fell into litigation and was dissolved in 1956 (W.B. Patten, personal communication, 1979).

Patten leased the claims to Lane Minerals, Inc., in 1957. Lane Minerals completed the road to the Coolidge adits and did considerable surface trenching and some underground development work. The company shipped about 20 tons averaging 57.2 grams/ton (g/ton) (1.67 oz/ton) gold and 48.0 g/ton (1.40 oz/ton) silver to the Tacoma, Washington, smelter in 1959. The price of gold, however, prevented serious development (H.E.L. Barton, personal communication, 1977).

Lane Minerals changed its name to Bohemia Minerals, Inc., in the mid-1960s. The claims were later deeded to H.E.L. Barton, a geologist, for services he provided Lane and Bohemia Minerals (H.E.L. Barton, personal communication, 1977).

This author purchased the original three claims from Barton in 1977. These claims were leased to James W. Edgar in 1979, and the lease was terminated 10 years later. A mapping and sampling program is in progress at the time this paper is being written.

Total production value from the mine has not exceeded $5,000. All production has come from the upper and lower Coolidge adits.

REGIONAL GEOLOGY

The Cascade Range is the product of arc volcanism that has been active since Eocene times (McBirney and others, 1974; Power, 1985). In Oregon, the Cascade Range has been subdivided into two belts of volcanic rocks, the Western Cascades of Eocene to Pliocene age and the High Cascades of Pliocene to Holocene age (Peck and others, 1964; Priest and others, 1983). The Bohemia mining district lies within the Tertiary Western Cascades province of Oregon.

The Western Cascades consist of flows, pyroclastic rocks, and volcaniclastic sediments that were deposited from numerous volcanic centers (Peck and others, 1964). Minor folding of the Western Cascades, along northeast-trending fold axes, occurred during several periods in late Eocene and late Miocene time (Peck and others, 1964). The High Cascades, consisting mainly of basaltic to andesitic flows and of stratovolcano complexes, fill a north-south-trending graben that developed in older volcanic rocks (Priest and others, 1983).

An active volcanic center existed in the Bohemia area during the Oligocene to early Miocene (Peck, 1960; Lutton, 1962). Interstratified flows and tuffs of basaltic to rhyolitic composition have been mapped and divided into three units (Figure 1) by Lutton (1962). The lower unit consists of over 300 m (990 ft) of massive dacitic to rhyolitic lapilli tuffs with locally intercalated tuffaceous sandstones and lacustrine shales. The intermediate unit (approximately 450 m [1,485 ft] thick) is characterized by dacites and rhyolitic dome complexes with onlapping flows and pyroclastics that fill erosional paleotopographic features in the massive tuffs of the lower unit. The upper unit (approximately 250 m [825 ft] thick) consists predominantly of basalt and andesite flows with minor dacite flows and intercalated lapilli tuffs. The granodioritic Champion stock and related plugs and dikes crosscut all volcanic units (Figure 1). Power and others (1981) determined an age of 21.7 m.y. for the Champion stock. Crosscutting relationships show that the epithermal veins of the Bohemia district postdate the Champion stock and are therefore younger than the associated volcanic and intrusive rocks.

LOCAL SURFACE GEOLOGY

The geology in the immediate vicinity of the claims is poorly understood. Lutton (1962) assigned the volcanic rocks in the claim group to the middle unit, which is composed of rhyolitic and dacitic dome complexes with onlapping flows and intercalated pyroclastic rocks. Numerous andesitic and basaltic dikes invade these volcanic rocks and are presumed to be feeders to the upper unit. A porphyritic dacite body crops out over a large area about 60 m (200 ft) or more southeast of the main adits on the Lincoln claim and parts of the Coolidge and Washington claims. Taber (1949) identifies this dacite body as a large intrusive. However, Lutton (1962) mapped the dacite as a large flow that crops out as far as Rock Creek canyon about 3.2 km (2 mi) to the southwest. The main President vein cuts through this dacite flow.

Several dikes occur nearly parallel to the President vein at the Coolidge adit. A lacustrine tuff is exposed in the hanging wall of the upper Coolidge adit, while the footwall is andesite. All volcanic rocks, including the dacite and local dikes, display pervasive propylitic alteration.

STRUCTURE

The President vein occupies a fault of unknown total displacement. This is most apparent at the upper Coolidge adit portal, where the hanging wall of the vein is a lacustrine tuff, and the footwall is a series of labradorite andesite flows. Presumably the footwall tuffs have been removed by erosion. A right-lateral component of movement is indicated by underground mapping.

The fault strikes N. 55°–60° W. and dips from 80° to vertical. The main ore zone on the Coolidge claim is located where the fault turns from N. 55° W. to N. 25° W.

Underground mapping indicates at least three periods of minor right-lateral movement, which has displaced earlier quartz-sulfide ore lenses and later carbonate-stibnite zones. The total lateral displacement is at least 15 m (50 ft). During right-lateral movement, tension fractures developed along a N. 25° W. direction and dilated, allowing ore deposition to occur in the Bughole drift (Figure 2). These tension fractures continued to dilate, keeping the Bughole portion of the vein open over an extended period of time.

Three phases of faulting are recognized (Figure 3). Phase 1 opened the fault so that lenses of quartz sulfide (stage II and III minerals) were deposited. These lenses were then offset approximately 3 to 5 m (10–15 ft) by phase 2 faulting, leaving a trail of

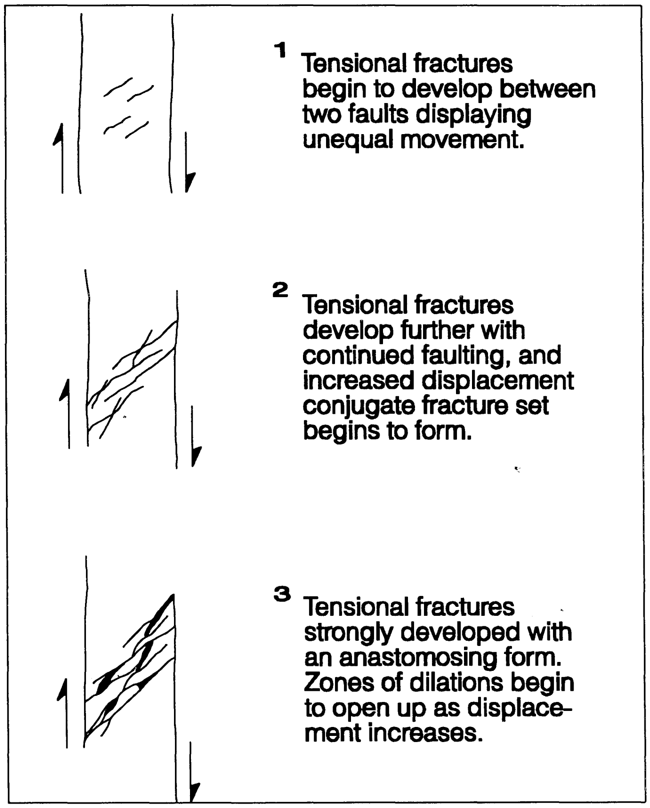


Figure 2. Model for development of tensional fractures at the President Mine (plan view, no scale).

breccia clasts between lenses that were incorporated into carbonate (stage IV) veining. Thus, the quartz-sulfide lenses appear staggered from hanging wall to footwall to hanging wall along the strike of the vein, with a more continuous carbonate vein dividing the quartz-sulfide lenses.

A third, postmineral faulting event (phase 3) further displaced the quartz-sulfide lenses and, to a lesser extent, the carbonate-stibnite veining. This third phase of faulting did not follow previous dilations in the Bughole area but took a new course, resulting in a split in veining at the Bughole drift. The Mattox drift follows this postmineral fault for about 21 m (70 ft), but no significant values were encountered. This late faulting is characterized by moderate brecciation, some gouge formation, and heavy postmineral oxidation. The total lateral displacement of the last two faulting events is about 7.5 to 9 m (25–30 ft).

McChesney (1987) noted right-lateral strike-slip faulting on the Sultana vein of the Miller Group in the northern portion of the Bohemia mining district. Two phases of faulting were observed. The first phase was subsequently mineralized by a gold-sulfide-quartz filling. This veining was then offset by a postmineral fault that paralleled the vein and locally offset it. McChesney proposed that this type of offset was a result of regional wrench faulting. The fact that right-lateral strike-slip faulting has been noted on the opposite side of the district at the President Mine lends credibility to this hypothesis. Gold mineralization at the President Mine is very different, however.

ALTERATION

Alteration types found at the President Mine include pervasive propylitic, sericitic, and argillic. Earlier propylitic alteration is overprinted by later sericitic and argillic assemblages.

The volcanic rocks show pervasive propylitic alteration throughout the Bohemia district. Locally, this alteration consists of chlorite

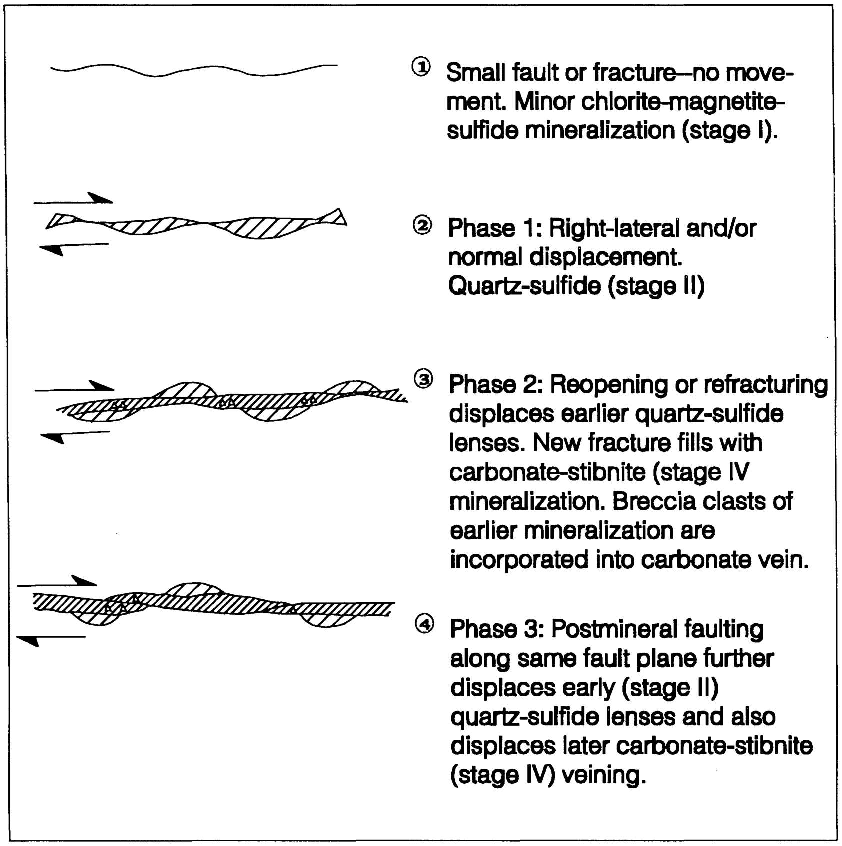


Figure 3. Faulting phases at the President Mine (plan view, no scale).

± epidote ± calcite + magnetite. Chlorite is pervasive and is found both as replacement of mafic minerals and within the groundmass. Epidote appears to be slightly later and is often structurally controlled. Calcite is often found both in the matrix and replacing plagioclase. Magnetite is a minor constituent of the various volcanic rocks locally.

The porphyritic dacite flow that crops out southeast of the main Coolidge adits shows pervasive sericitic alteration over a large area. The rock generally appears bleached from sericite replacement of both mafic minerals and groundmass. Minor silicification with disseminated pyrite is locally present. The dacite hosts a swarm of phenocryst overgrowth veinlets similar to those at Round Mountain, Nevada, which rarely exceed 5 mm in width. No disseminated-type precious metal mineralization has been identified.

Sericitic alteration forms 0.3- to 3-m (1–10 ft) envelopes in all rock types around the President vein. This alteration consists of sericite, pyrite, and local silicification. Sericite replaces both mafic minerals and groundmass. Pyrite occurs as 1-mm cubes disseminated in the volcanic rocks around the vein. Silicification often occurs as 5- to 20-mm envelopes around quartz veining. Sercitic alteration appears to be related to quartz-sulfide mineralization of stages II and III.

Carbonate minerals occur in an alteration envelope from 1.5 to 4.5 m (5–15 ft) around the President vein. Carbonate replaces both plagioclase and groundmass and is most intensely developed around stage IV dolomite veining. Silicified areas do not contain carbonate.

Argillic alteration occurs as an outer alteration envelope around sericitic zones. At the President Mine, argillic alteration mainly has kaolin replacing feldspar phenocrysts. Groundmass can look slightly bleached in some locations but often is fresh looking in hand specimens. Argillic alteration at the President Mine is volumetrically unimportant compared to sericitic alteration.

VEIN MINERALOGY

Five stages of mineralization have been identified in the President vein system. These five stages have been classified based on crosscutting relationships, brecciation, and colloform banding. Oxidation followed these mineralization events.

Stage I

Chlorite, epidote, magnetite, quartz, and carbonate characterize the earliest stage of mineralization at the President Mine. This mineralization is part of the district-wide alteration of the host volcanic rocks and is related to contact metamorphism and emplacement of the Champion stock (Katsura, 1988). Locally, in addition to pervasive propylitic alteration, small veinlets and crackle breccias cemented by quartz chlorite can be found in the President vein. These veinlets occur in breccia clasts incorporated into the mineralization of stages II, III, and IV.

Stage II

The beginning of stage II quartz-sulfide mineralization is marked by a faulting and brecciation event (phase 1 faulting) that opened the President fault, allowing open-space filling by quartz and various sulfides in swells of the fault. The quartz is coarsely crystalline and exhibits crustification and colloform banding. The quartz contains various amounts of pyrite (1–2 percent), sphalerite (<1 to 5 percent), chalcopyrite (<1 to 2 percent) and galena (2–6 percent). Crustification banding suggests that sphalerite was dominant during the early stages of stage II, while chalcopyrite and especially galena became dominant later. Pyrite is ubiquitous.

Stage III

The transition from the end of stage II to the beginning of stage III is not clear, but it is thought to be marked by the first of two brecciation events. Stage III is similar to stage II except for specular hematite, which gives the quartz that cements breccia a purple hue. Galena and chalcopyrite dominate this phase, while sphalerite is subordinate.

Both stages II and III are similar to the typical, district-wide quartz-sulfide mineralization found on many mine dumps in the Bohemia area. However, galena is more abundant at the President Mine, similar to the Musick Mine (Callahan and Buddington, 1938). The quartz-sulfide mineralization at the President Mine occurs in discrete lenses rather than in continuous veins. Precious metal values in stages II and III are low; typically less than 0.7 g/ton (0.02 oz/ton) of gold and 0.3 g/ton (0.01 oz/ton) of silver.

Stage IV

Stage IV is marked by both a large brecciation event (phase 2 faulting) and a radical change in vein mineralogy. Presumably, a long time interval separated stage III and stage IV mineralization. The large brecciation event that marks the beginning of stage IV mineralization is presumably the result of phase 2 faulting, which split and offset earlier quartz-sulfide lenses (Figure 3). A trail of quartz-sulfide breccia clasts between sulfide lenses is incorporated into stage IV mineralization. Stage IV mineralization is dominated by dolomite that hosts stibnite, galena, pyrite, and quartz containing auriferous pyrite plus minor chalcopyrite, galena, and sphalerite.

A scanning electron microprobe of the dolomite gangue indicates a high-iron, high-manganese dolomite. The iron content is not high enough to classify the dolomite as ankerite. Differences in the degree of weathering suggest that earlier dolomite has a higher iron content than dolomite deposited later in sequence.

Galena is often found as coarse cubes at the wall-rock contact with dolomite. It is usually not found hosted within the dolomite away from wall-rock contacts and represents the earliest sulfide of stage IV mineralization.

Stibnite occurs as spectacular radiating clusters of needlelike crystals up to 20 cm (8 in.) long, hosted by the dolomite gangue. The stibnite occurs in elongate pods or lenses with nearly vertical rake. Locally, these pods may assay as high as 40 percent antimony. Galena is often along the wall-rock contacts of the stibnite lenses.

Following the initial dolomite, stibnite, and galena deposition, repeated brecciation occurred, followed by dolomite and then quartz-sulfide-gold infill mineralization. The dolomite and quartz consist of paired sequences of early, off-white-colored dolomite bands that are followed by clear quartz in thin bands which host sulfides. These paired sequences are repeated several times but are complicated by intervening brecciation so that later paired bands of dolomite and quartz crosscut earlier bands.

The quartz often occurs as casts or molds of calcite scalenohedra within the dolomite, yet no calcite is present. This suggests that dolomite may have replaced earlier calcite so that the only indications of calcite remaining are molds of the calcite crystals by quartz. Some casts indicate crystals up to 5 cm (2 in.) long.

Thin sections cut across the paired bands of dolomite and quartz show that the dolomite does not contain gold. Assays of dolomite without quartz indicate a low gold content of less than 1.0 g/ton (0.03 oz/ton) of gold.

However, the thin sections reveal electrum in the quartz bands of the paired sequence. The electrum occurs on the faces of pyrite cubes or as apparent exsolution blebs within the pyrite. Chalcopyrite, galena, and sphalerite are also present in subordinate amounts. Portions of the President vein that contain paired sequences of dolomite and quartz sulfides typically assay from 17 g/ton (0.50 oz/ton) to 86 g/ton (2.50 oz/ton) gold. Silver occurs in a roughly 1:1 ratio with the gold.

Brecciation and recementing of dolomite was common during phase 3 faulting. At least three distinct brecciation events are recognized. Associated with these brecciation events are vein sediments that occupy vugs in the dolomite. These sediments exhibit typical sedimentary features, such as grading, slump structures, and deformation by larger pebbles. The bedding is perfectly horizontal, indicating no tilting of the vein since sediment deposition.

The sediments are composed chiefly of very fine grained dolomite and silica. Small particles of pyrite are sometimes found in certain beds, as well as stibnite and galena. These sediments indicate areas of relatively calm fluid flow within the President vein during the time they were deposited (Schieber and Katsura, 1986). They are roughly analogous to clastic dikes. These sediments plus the nature of the breccia suggest that the breccia is hydrothermal rather than mechanical in origin. However, the breccia could also be a result of continued fault movement and reopening (widening) of the tension fractures. Vein sediments have been found as breccia clasts cemented by later dolomite.

Schieber and Katsura (1986) discussed vein sediments from the Bohemia mining district in some detail. Figure 3 in their article shows a sample from the lower Coolidge adit of the President Mine. They interpreted these sedimentary features as sedimentary accumulations due to calm fluid flow adjacent to areas of boiling. Banding is due to episodic flow from episodic eruptions or boiling of fluids. Thus, most breccias formed during vein sedimentation are the result of hydrothermal brecciation. The fact that vein sediments occur only during the carbonate stage IV period suggests that boiling occurred during stage IV.

Stage V

Following the quartz-pyrite-gold phase were minor refracturing and stage V calcite mineralization. The calcite occurs as coarsely crystalline scalenohedra that line vugs and open fractures within the

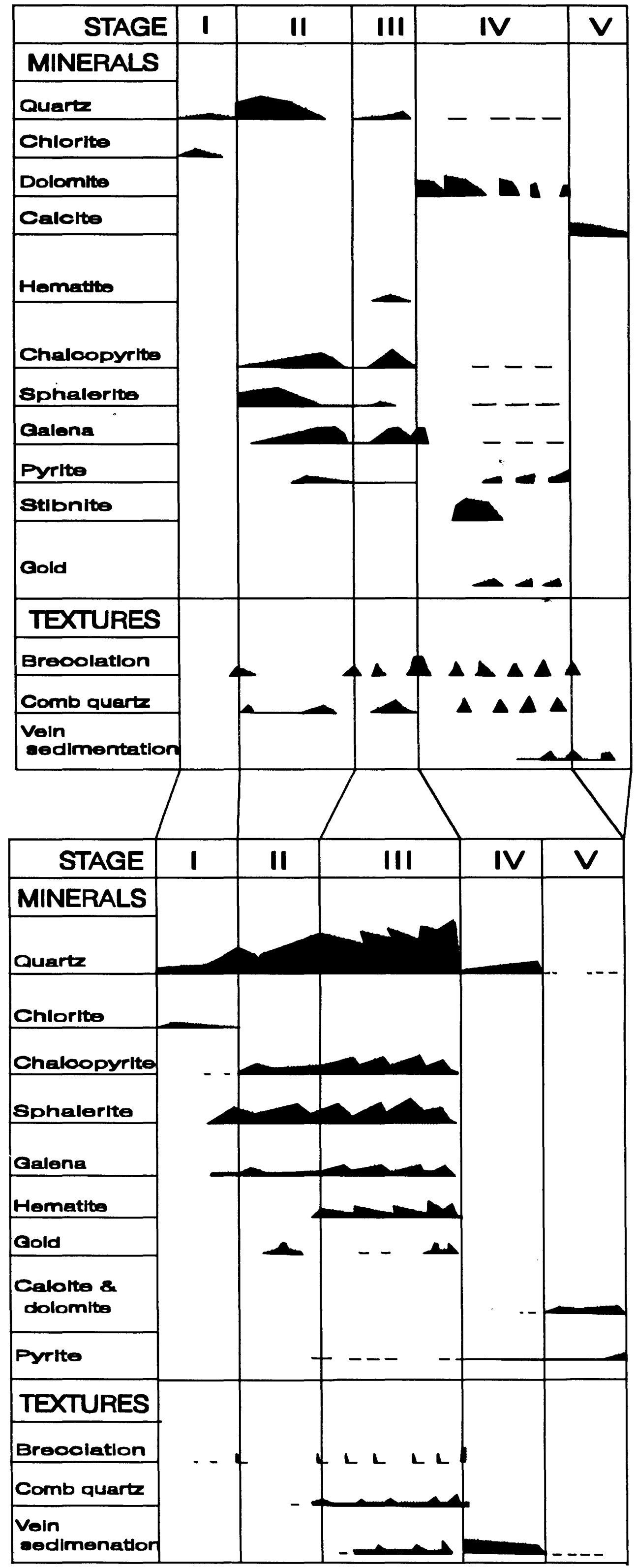


Figure 4. Generalized paragenetic sequence of minerals, brecciation events, and vein sediments at the President Mine (above) and the Champion Mine (below) and the correlation between them. The height of blackened areas indicates relative abundance of minerals or features. Modified from Schieber and Katsura (1986).

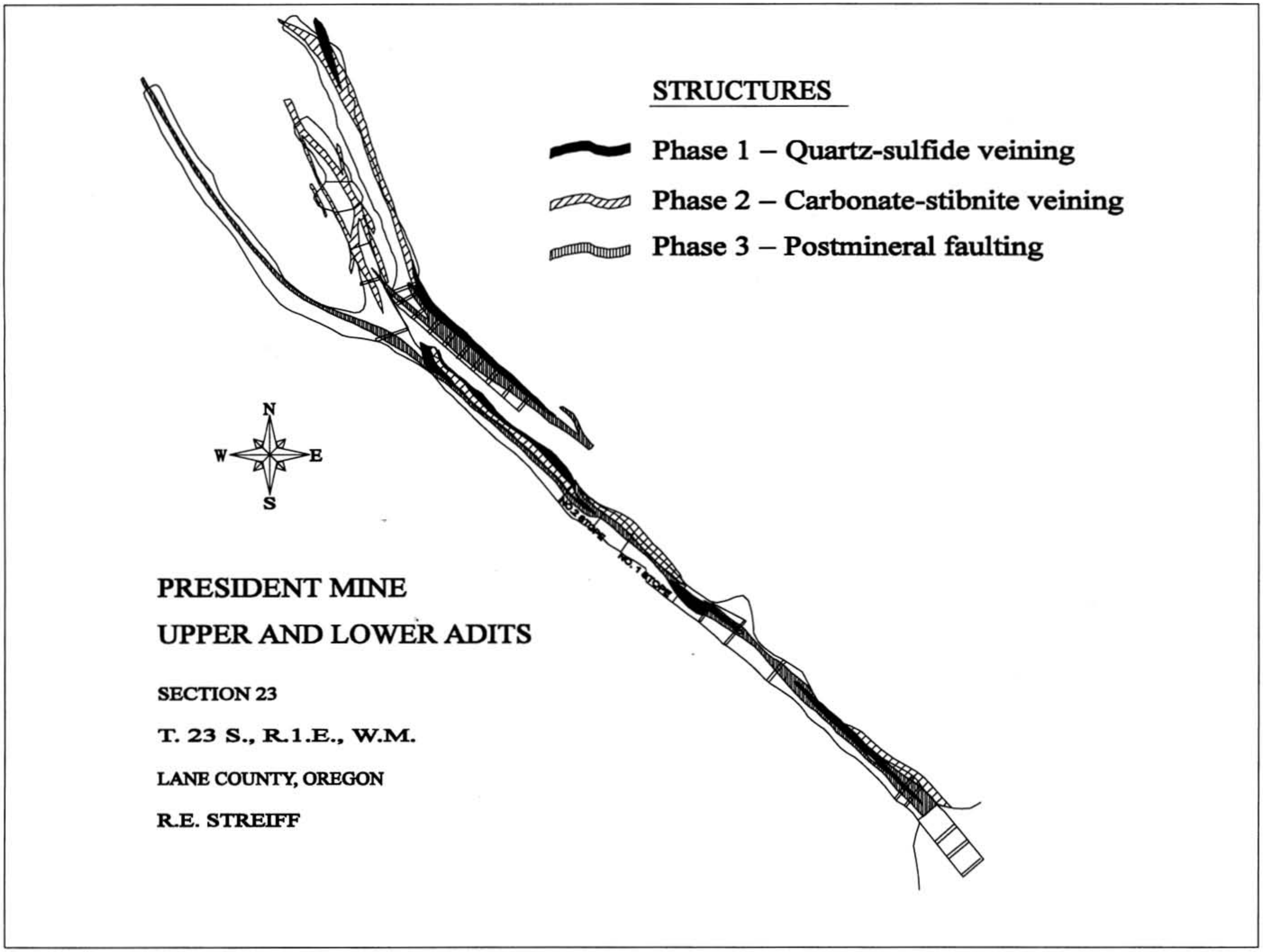


Figure 5. Geologic map of the upper and lower Coolidge adits at the President Mine (plan view, no scale).

vein. Several incompletely filled areas of the dolomite veining contain calcite scalenohedral crystals up to 5 cm (2 in.) long. Locally, the calcite is sometimes brown or black in color. Some vugs are up to 45 cm (18 in.) wide, 6 m (20 ft) long, and 9 m (30 ft) high and are faced with calcite crystals. This late calcite contains no sulfides and is low in gold and silver.

Oxidation

Oxidation and weathering of the deposit occurred following the calcite stage. The carbonates were particularly susceptible to weathering and are responsible for much of the residual limonite and manganese minerals. Sulfides were mainly leached away, so that the net result was a slight upgrading of gold in the oxidized zone and a liberation of fine gold from encapsulation. Some of this gold migrated downward in the vein through the numerous open spaces provided by weathering and already present in the vein, similar to placer gold (Lutton 1962). Pockets of residual fine gold (placer-type) have been found in the lower oxidized zone, particularly in the bottom of large, open cavities.

Fine gold liberated during oxidation may also have been moved chemically, probably by manganese, to the lower oxidized zone and recrystallized on the surface of goethite pseudomorphs in coarser leaves and wires. The importance of this chemical enrichment in the deposit has probably been overestimated, however.

Erosion has been rapid in the Saint Peter Creek canyon, which is narrow with very steep walls. Therefore, the level of oxidation is relatively shallow (60 m [200 ft]), since the outcrop is stripped off by erosion shortly after oxidation.

Cerussite is not uncommon in the oxidized zone, occurring as small greenish-yellow crystals. Stibiconite can sometimes be identified when pseudomorphed after stibnite. Some perfectly translucent, coarsely crystalline quartz lines limonite-stained vugs and boxwork and is probably a late supergene remobilization of earlier quartz of stages II and III existing in the vein. In some cases, this quartz can clearly be seen postdating initial oxidation of the host vein rock.

Figure 4 shows the generalized paragenetic sequences of the Champion and President Mines and the correlation between them. Overall, the two mines compare reasonably well. Most of the stages of the Champion Mine are represented in the President, although the volume and thus importance of each stage vary considerably.

DISCUSSION

Crustification, colloform banding, and anomalous antimony, arsenic, and mercury geochemistry at the President Mine are characteristic of epithermal deposits. Epithermal characteristics in the Bohemia district have been noted by Lutton (1962), McChesney (1987), and Katsura (1988).

The President epithermal vein system (Figure 5) occupies a fault with at least 15 m (50 ft) of displacement. Fault movement was episodic. Rake of the gold ore zones and lenses of stibnite suggest normal dip-slip with a small component of right-lateral movement, but the actual displacement direction and amount are uncertain. Mapping indicates right-lateral displacement, however.

The typical Bohemia-style quartz-sulfide mineralization (stages II and III) occurs in discontinuous lenses along a single fault plane. The quartz-sulfide mineralization does not host significant precious metal mineralization. Alteration is dominantly sericitic. These features suggest that stages II and III represent a deeper portion of an epithermal vein system, below the zone of precious metal mineralization. The influx of stage III hematite implies a decrease in available sulfur as the quartz-sulfide stages waned. This increase in hematite over time is opposite of the Champion Mine (Katsura, 1988) but similar to the Sultana vein (McChesney, 1987).

The mineralization and overall morphology of stage IV are radically different from previous stages. Unlike previous mineralization, stage IV veining is both anastomosing and bifurcating. Dolomite is the dominant gangue mineral. Stibnite is a significant sulfide. Electrum-bearing pyrite is the major gold occurrence at the President and is contained within stage IV only. All of these features suggest that stage IV is an upper level epithermal event, while stages II and III represent deep epithermal mineralization below the precious metals horizon.

This elevational difference can be explained if one assumes a hiatus between stages III and IV. During this hiatus, rapid erosion lowered the land surface considerably. The depositional hiatus was broken by renewed fault movement at the onset of stage IV. Rapid erosion of the Bohemia volcanic complex would also explain the increase in anomalous antimony, arsenic, and mercury noted at the Champion (Katsura, 1988) and Sultana (McChesney, 1987) Mines over time as well as at the President Mine. However, changes in the overall chemistry of the evolving system and proximity to the Champion stock probably also impacted the mineralogy of the veins. A collapse of the Bohemia hydrothermal system with age probably contributed significantly to the district-wide paragenetic sequence.

ACKNOWLEDGMENTS

I wish to thank Bruce Stewart for permission to publish the data contained within this paper. Special thanks go to Kurt Katsura, who provided hours of discussion and granted permission to use portions of his papers on the Champion Mine.

The manuscript was reviewed by Dorinda Bair and Thomas Hanna. Kris Itza typed the manuscript and the various revisions. Chuck Swisher drafted all of the illustrations.

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Late Cenozoic tectonics and paleogeography of the Salem metropolitan area, central Willamette Valley, Oregon

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ABSTRACT

Logs from 360 water wells, oil wells, and engineering drill holes were used to resolve the structure of the Columbia River Basalt Group and the overlying sequence of valley fill. The regional structure is controlled by the Willamette Valley synclinorium. Short northeast- and northwest-trending faults subdivide this area into the Stayton and northern Willamette structural basins separated by a zone of uplift, the Waldo Hills. Neogene uplift of the Waldo, Salem, and Eola Hills formed a tectonic dam that caused fine-grained alluvial sediments associated with the ancestral Willamette River system to accumulate in the southern Willamette Valley. Overlying these sediments are alluvial and braided-stream gravels deposited as glacial outwash from the North Santiam River drainage. This buried gravel fan traverses the Waldo Hills uplift through a 1-km-wide channel connecting the Stayton and northern Willamette basins. Thickening of the gravel fan indicates that the northern Willamette basin was actively subsiding during its deposition. Magnetostratigraphy combined with fossil pollen data from a 40-m-long drill core tentatively date the fan deposit as Pliocene to middle Pleistocene. Holocene uplift of the Salem-Eola Hills homocline relative to the northern Willamette basin is suggested by a broad convexity in the modern longitudinal profile of the Willamette River. Although the long-term rates of vertical deformation are very low, on the order of 10^{-2} mm/year, the magnitude 5.6 earthquake of 1993 near Scotts Mills demonstrated that intracrustal deformation is continuing.

INTRODUCTION

This paper describes the late Cenozoic structure, depositional history and paleogeography of the Salem metropolitan area. Logs from 360 drill holes were used to resolve the structure of an 800-km^2 area centered around the city of Salem (Figure 1). The database was assembled by gathering, field-locating, and interpreting logs of water wells, oil wells, and engineering drill holes obtained from the Oregon State Engineer's office, the Oregon Department of Transportation, the U.S. Geological Survey Water Resources Division, and previous studies including Hampton (1963, 1972), Helm and Leonard (1977), and Burns and Caldwell (in preparation). Integrating drill hole data with the surface geology, we constructed structure contour maps and cross sections of the Columbia River Basalt Group and the overlying valley fill. The project also included magnetostratigraphic analyses of two drill cores.

TECTONIC SETTING

The Willamette Valley/Puget Sound lowland is a forearc basin that lies on the convergent margin of the North American continent. This regional downwarp is largely the result of simultaneous late Cenozoic uplift of the Cascade Range and the Coast Range, which enclose the Willamette Valley (Beeson and others, 1989; Priest, 1990; Yeats and others, 1991). West of the valley, tectonic growth throughout the late Cenozoic arched Paleogene continental-shelf sediments into a broad anticlinorium that now forms the present-day Coast Range (Yeats and others, 1991; Niem and others, 1992). In the valley itself, Miocene strata are downwarped to form an elongate structural depression known as the Willamette Valley synclinorium (Beeson and others, 1989; Yeats and others, 1991).

Discontinuous northeast- and northwest-trending faults subdivide the Willamette Valley into a mosaic of fault-bounded blocks (Yeats and others, 1991). In the north half of the valley, differential subsidence of these blocks created a series of structural subbasins, which include the Portland basin, the Tualatin basin, the northern Willamette basin, and the Stayton basin (Beeson and others, 1989; Yeats and others, 1991; see Figure 1). Linked by the Willamette River system, these bedrock-rimmed basins were progressively infilled with thick sequences of nonmarine strata. In contrast, the southern valley is a single large basin that contains one continuous body of basin fill.

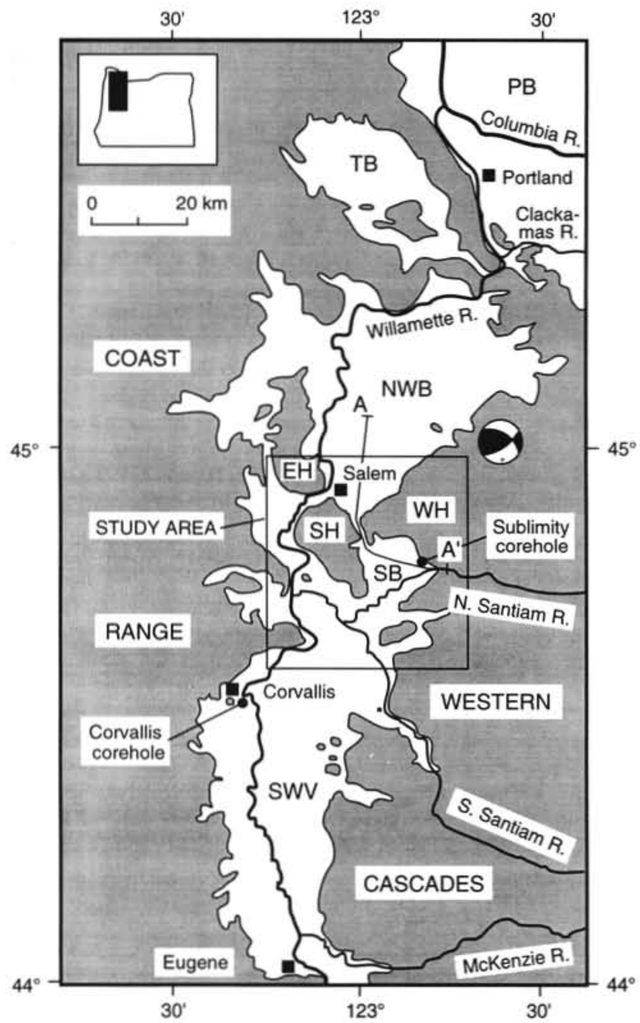


Figure 1. Physiographic map of the Willamette Valley, showing major rivers, the focal mechanism of the magnitude 5.6 Scotts Mills earthquake of 1993 (from Dewey and others, 1994), and the boundaries of the study area. PB = Portland basin, TB = Tualatin basin, NWB = Northern Willamette basin, SB = Stayton basin, EH = Eola Hills, SH = Salem Hills, WH = Waldo Hills, SWV = southern Willamette Valley.

STRATIGRAPHY

Columbia River Basalt Group (middle Miocene)

The Columbia River Basalt Group is a series of flood basalts that originated from vents in northeastern Oregon, southeastern Washington, and western Idaho (Wells and Peck, 1961; Mangan and others, 1986; Beeson and others, 1989). In a massive pulse of magma extrusion, flow units of the Grande Ronde Basalt completely inundated the northern Willamette Valley, extending as far south as Franklin Butte (Beeson and others, 1989). These flows, the first to reach the Salem area, account for the bulk of flood basalt in the Willamette Valley. Thin flows of the Wanapum Basalt traversed the broad surface formed by the Grande Ronde Basalt, filling structural depressions, broad erosional channels, and topographic lows along its margins (Beeson and others, 1985, 1989). Seven potassium-argon dates from Grande Ronde and Wanapum Basalt in the study area cluster between 14.0 ± 0.2 Ma and 15.6 ± 0.8 Ma (Lux, 1982; Walker and Duncan, 1989).

The valley fill

Global climatic change in the Pliocene-Pleistocene led to glaciation of the Cascades and loaded the eastern tributaries of the Willamette River with glacially derived sediments. Glacio-fluvial outwash spilled into the Willamette Valley and migrated across the valley floor as massive, aggrading fans. Three terraces, underlain by the Lacomb, Leffler, and Linn gravels, record the latest pulses of glacio-fluvial sedimentation (McDowell, 1991). The Lacomb and Leffler gravels form west-sloping (0.5°–1°) terraces, preserved mainly in drainages exiting the Western Cascades, while the youngest glacial-fluvial deposit, the Linn gravels, underlies most of the valley floor (Allison, 1953; Allison and Felts, 1956; Beaulieu and others, 1974; Yeats and others, 1991). Radiocarbon age estimates for the Linn gravels range from $28{,}480 \pm 1{,}810$ to > 40,000 years B.P. (Glenn, 1965; Balster and Parsons, 1969; Roberts, 1984).

Thick gravel deposits in the subsurface are interpreted to be composites of glacio-fluvial outwash fans and older fluvial deposits predating glaciation (Gannett, 1992). Yeats and others (1991) proposed that the deep gravels in the southern Willamette Valley represent a channel facies of the proto-Willamette River that was buried beneath a sheet of glacial outwash. Most of these gravels, however, coincide with major tributary drainages from the Western Cascades and do not define an ancestral course of the Willamette River (Gannett, 1992). The two largest gravel fans, associated with the Willamette and North Santiam Rivers, extend down the center of the valley, but they also grade laterally into fine-grained sediment (M. Gannett, U.S. Geologic Survey, Water Resources Division, Portland, Oregon, written communication, May 27, 1993) and are, therefore, not part of a continuous channel deposit.

The lower section of the valley fill, known informally to water-well drillers as "the blue clay," consists predominately of fine-grained facies (Trimble, 1963; Hampton, 1972; Helm and Leonard, 1977; Yeats and others, 1991). In the northern Willamette Valley, moderately to poorly lithified siltstone, sandstone, mudstone, and claystone, commonly containing wood, crop out along the banks of the Clackamas and Sandy Rivers. This unit, named the Sandy River Mudstone by Trimble (1963), may correlate with the fine-grained sediments in the southern and central Willamette Valley that have been documented in drill holes near Monroe, Lebanon, Corvallis, and Sublimity (Roberts and Whitehead, 1984; Niem and others, 1987; Yeats and others, 1991).

The depositional environment of the fine-grained facies is not well understood, although both lacustrine and overbank origins have been proposed (Roberts and Whitehead, 1984; Yeats and others, 1991). The widespread existence of fine-grained sediment in the lower section of the valley fill may reflect a period of low sediment output from lower-relief topography in the Miocene.

Lithostratigraphy of the Salem metropolitan area: The valley-fill sequence in the study area compares well with the regional stratigraphy of the Willamette Valley. Drill hole logs show that the valley fill is divided into a lower section and an upper section. The upper section consists chiefly of gravel with varying amounts of sand, silt, and clay and is up to 100 m thick (Figure 2). Maximum clast sizes range from pebble to cobble, with boulder-sized clasts reported locally at the surface, particularly in the Stayton basin. Also

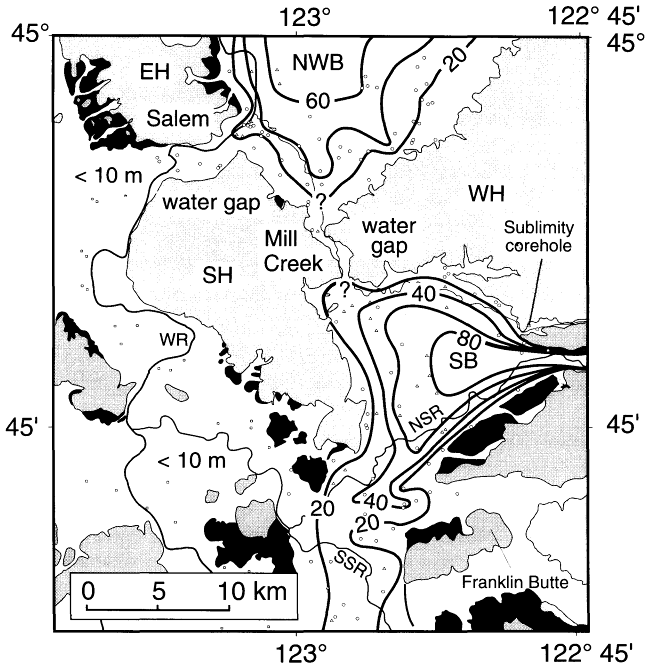


Figure 2. Isopach map of gravels underlying the surface of the Linn fan, in meters. Older terrace gravels, after Yeats and others (1991), are shown in black. Open circles = wells penetrating the base of the gravel deposit, open triangles = wells providing a minimum thickness, open squares = approximately located wells from Yeats and others (1991). WR = Willamette River, NSR = North Santiam River, SSR = South Santiam River.

present are thick sections of fine-grained sediment at small drainages, including Mill Creek, McKinney Creek, and the Pudding River (Figure 3). Interfingering and lateral juxtaposition with gravels suggest these sediments were deposited on the distal reaches and margins of gravel outwash fans. The lower section of the basin fill is dominated by fine-grained sediments consisting of sand, silt, and clay. Detailed drill hole logs commonly report alternating layers of finer and coarser material, and some logs note minor intervals of gravel (up to 2 m thick), wood (up to 7 m thick), and volcanic ash. In the center of the Stayton basin, the maximum thickness of fine-grained sediments is 115 m (Figure 3).

Gravels comprising the upper section of valley fill in the study area form a massive alluvial fan that extends across the Stayton basin and into the northern Willamette basin (Figure 4). This fan is buried beneath a wedge of late Pleistocene catastrophic flood deposits, which is thickest in the northern Willamette basin. Structure contours on the top of the gravel facies show the constructional surface of the youngest outwash deposit, the Linn gravels (Figure 5). The fan surface bifurcates against the Salem Hills and extends into the northern Willamette Valley through a 1-km-wide water gap occupied by Mill Creek, demonstrating that the ancestral North Santiam River transported Linn gravels into the Willamette basin.

We infer that the ancestral North Santiam River is the primary source for the deep gravels in the Salem metropolitan area, because (1) these gravels form a continuous fanlike geometry; (2) no other

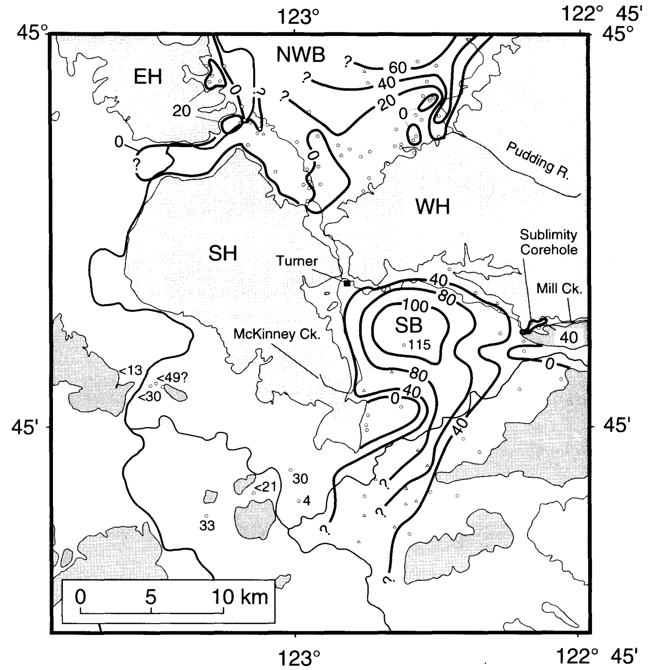


Figure 3. Isopach map of fine-grained sediments in the valley fill. For symbols and abbreviations, see Figures 1 and 2. Numbers in smaller type are thicknesses in meters interpreted from adjacent oil wells. Contour interval is 40 m with supplemental contours at 20 m.

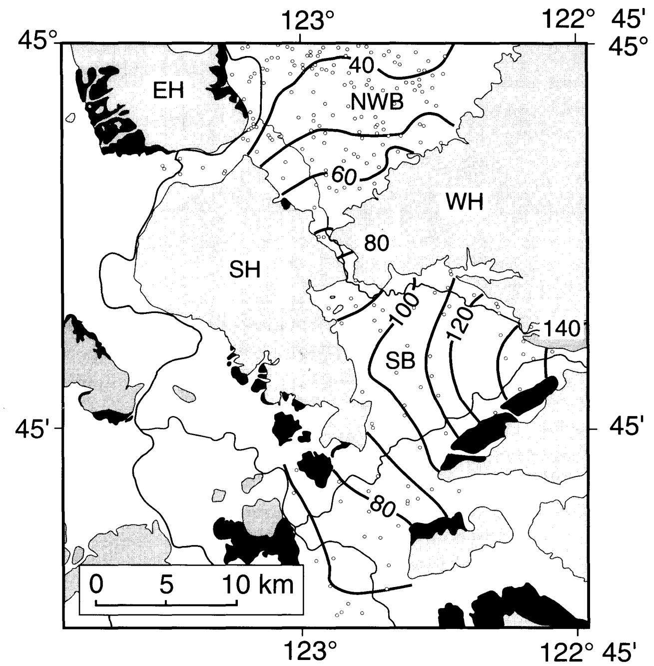


Figure 5. Structure contour map of the top of Linn gravels. Open circles = wells penetrating the upper gravel section of the valley fill. Older terrace gravels, after Yeats and others (1991), are shown in black. Contour interval is 10 m.

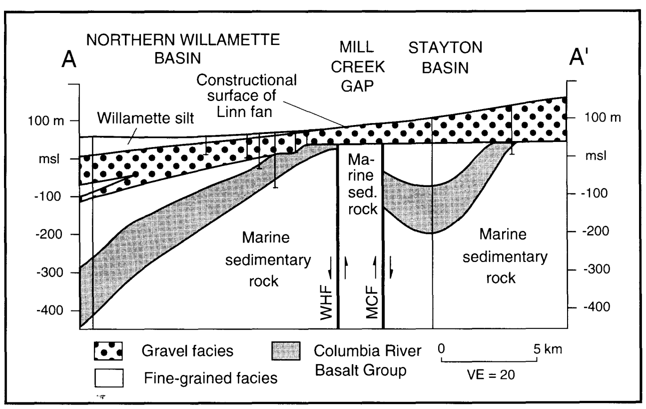


Figure 4. Geologic cross section through the Mill Creek water gap along the crest of the Linn gravel fan, showing fan gravels deposited by the ancestral North Santiam River and well control. Section location shown in Figure 1.

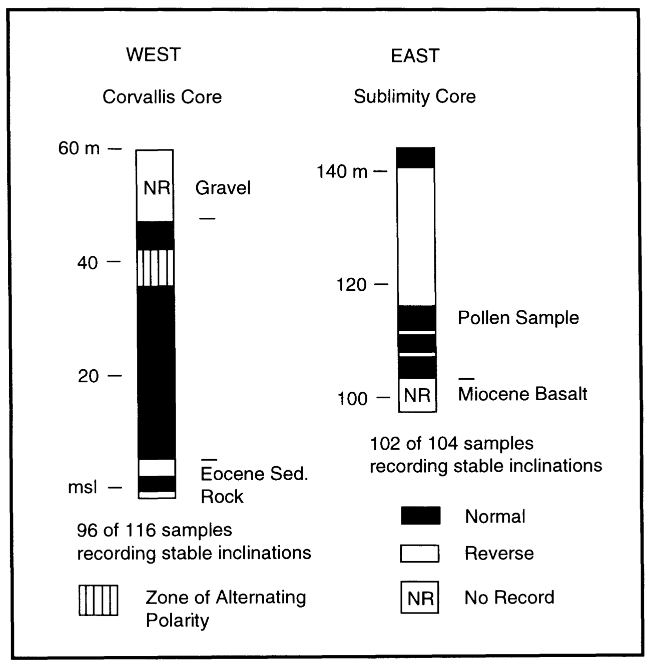


Figure 6. Magnetic polarity of cores drilled by the Oregon Department of Transportation at Corvallis and Sublimity. Core hole locations shown in Figure 1.

drainages, aside from the Willamette River, are capable of transporting a large volume of gravels into the south end of the northern Willamette basin; and (3) gravels along the course of the Willamette River are thin and discontinuous and do not form a thoroughgoing channel deposit (M. Gannett, written communication, 1993).

Core-hole magnetostratigraphy: In holes near the towns of Corvallis and Sublimity (Figure 1), the Oregon Department of Transportation continuously cored sections of the valley fill with about 90 percent recovery. Alternating-field and thermal demagnetization of specimens from these cores yielded stable remanent magnetic inclinations. The polarity log of the Sublimity core shows a long reverse segment bounded above and below by predominantly normal polarity zones (Figure 6). The Corvallis core is mostly normal except for one zone of alternating polarity at about 40 m mean sea level (MSL), which is considered unreliable, because each reverse interval is a one- or two-sample spike, and the specimens have relatively unstable remanence. The reverse polarity segment at the bottom of the Corvallis core is in the Eocene Spencer Formation (Yeats and others, 1991).

Fossil pollen, sampled from a depth of 31.8 m in the Sublimity core, were analyzed by C. Whitlock at the University of Oregon. The pollen assemblage suggests a period of open parkland with spruce and pine as the dominant conifers. An herb indicative of alpine conditions is also present, while exotic taxa are absent (C. Whitlock, written communication, 1992).

Because no significant reversals are recognized in the Brunhes geomagnetic-polarity epoch (or chron), the long reverse polarity zone in the Sublimity core indicates that the cored sediments below 140 m MSL are older than 0.78 Ma (Hilgen, 1991; Zijderveld and others, 1991). Correlation of the long reverse zone with the Matuyama chron is preferred, given a glaciofluvial outwash interpretation for the core sediments (discussed later). However, based on the paleomagnetic data alone, the possibility that the reversely magnetized sediments belong to the Gilbert chron can not be excluded. The pollen assemblage is more consistent with a Matuyama interpretation, because it is suggestive of a climate cooler than today's. Thus, the Sublimity core probably records Pliocene to middle Pleistocene sedimentation.

STRUCTURE

Figure 7 summarizes the late Cenozoic structure of the study area. Identification of these structures is based largely on deformation of the Columbia River Basalt Group. Therefore, inferences about flow emplacement in the northern Willamette Valley are crucial to interpretation of the tectonic history. The basic assumption is that the top of the Columbia River Basalt Group originated as a relatively planar surface, providing a datum from which vertical tectonics can be measured. We believe this assumption is valid, because the great areal extent, long distance from the source, and huge volume of these lavas, particularly the Grand Ronde Basalt, are indicative of fluid flow conditions.

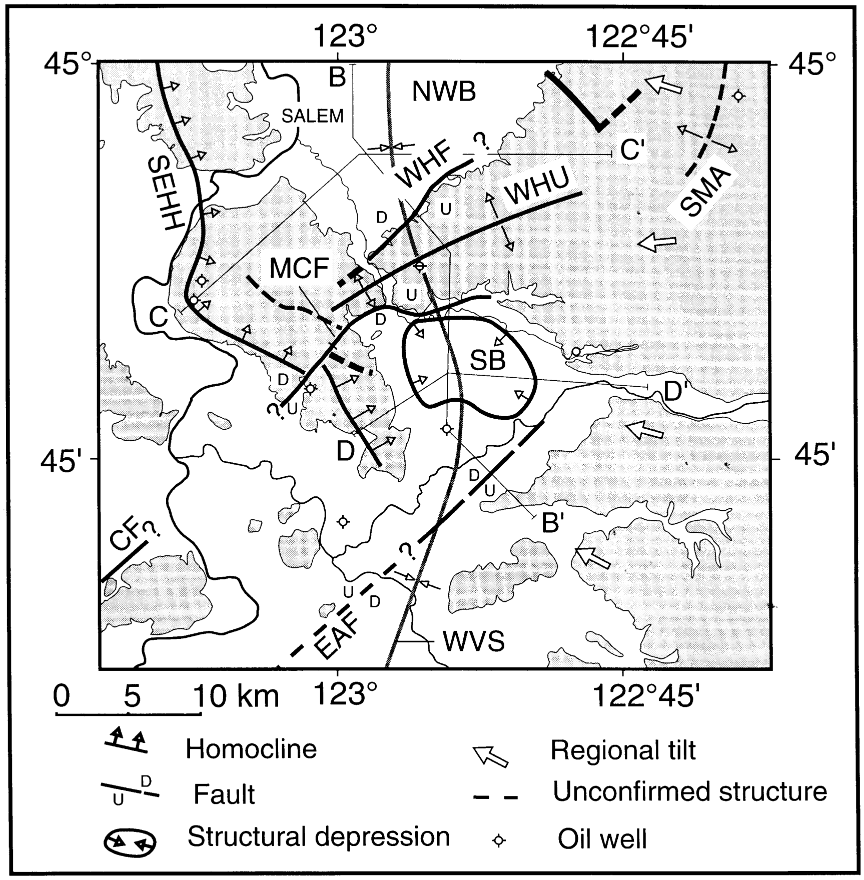


Figure 7. Neotectonic map showing structures that deform the Columbia River Basalt Group. WVS = Willamette Valley synclinorium, SEHH = Salem-Eola Hills homocline, WHF = Waldo Hills fault, MCF = Mill Creek fault, WHU = Waldo Hills uplift. Structures on which no post-Columbia River Basalt Group activity is documented include the Scotts Mills anticline (SMA), the east Albany fault (EAF), and the Corvallis fault (CF).

Willamette Valley synclinorium

In the study area, the Columbia River Basalt Group is warped into a north-south-trending structural trough that comprises the core of the Willamette Valley synclinorium (Figures 8b and 9). The east limb of this trough is characterized by gently westward dipping basalt (about 1.7°) in the foothills of the Western Cascades. Similarly, the west limb of the trough is marked by northeast-sloping cuestas comprising the Salem Hills and Eola Hills. Structure contours show that the basalt in these hills tilts 2°– 4.5° northeast (Figure 8). Beeson and others (1989) first recognized these cuestas as tectonic features, naming them the Salem-Eola Hills homocline. The northeast dip direction of the homocline suggests that it is more a result of local tilting on the margins of the northern Willamette and Stayton structural basins than regional tilting on the eastern slopes of the Coast Range. The maximum structural relief on the Columbia River Basalt Group between the Salem Hills and the northern Willamette basin is 820 m (Yeats and others, 1991; this study).

Stayton basin

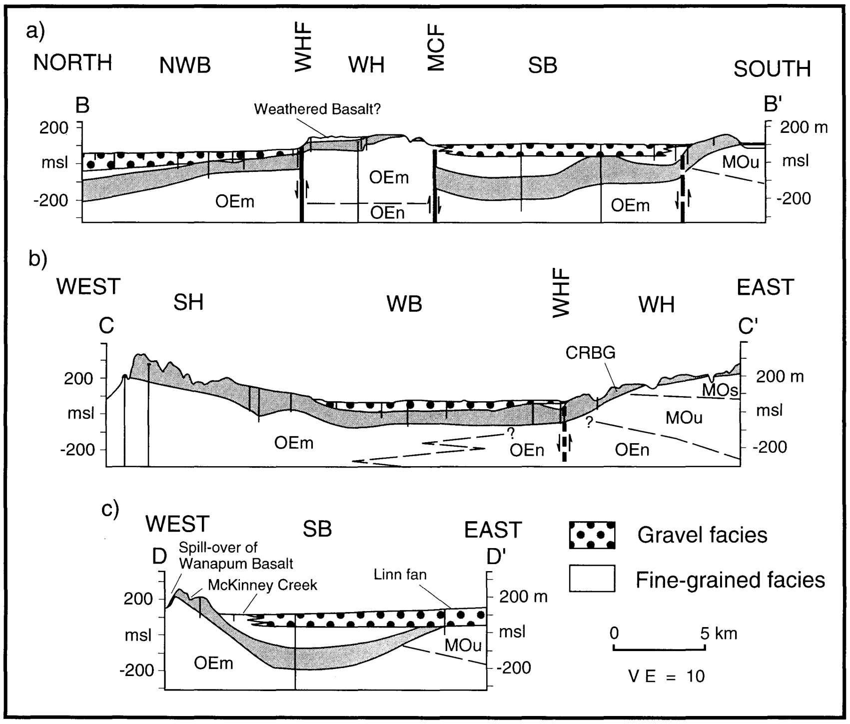
The Stayton basin is an oblate depression with 400 m of structural relief on the top of the Columbia River Basalt Group (Figure 9). The pattern of deformation is that of a northwest-trending fold bounded by high-angle faults orthogonal to the fold axis. Broad downwarping controls subsidence at the southwest and northeast margins of the basin, while a northeast-trending fault pair controls subsidence at the northwest and southeast margins (Figures 8a, 8c, 9). At the northwest margin, vertical displacement on the Mill Creek fault is pronounced. Faulting along the southeast margin is less clear, but water wells constrain a steep drop of at least 80 m in the upper surface of the basalt.

Basalt at the southwest margin of the basin tilts eastward at 4.5°, roughly twice that of basalt in the northern Salem Hills and Eola Hills (Figures 8b, 8c, 9). This contrast in dip demonstrates that the wavelength of folding in the Stayton basin is shorter than that of the synclinorium and the northern Willamette basin, and hence the Stayton basin must have subsided independently.

Folding of the Stayton basin may reflect sag into a pull-apart structure associated with lateral-slip faults bounding the basin. This interpretation is similar to that for the Portland basin, which is bound by dextral strike-slip and dip-slip faults (Beeson and others, 1989; Yelin and Patton, 1991) and is consistent with the current north-south compressive stress of western Oregon (Werner and others, 1991).

Northern Willamette basin

The northern Willamette basin is a northeast-southwest elongate depression that straddles the regional downwarping axis of the Willamette Valley. Up to 550 m of basin fill overlies the Columbia River Basalt Group, which, in the center of the basin, has subsided to 500 m below sea level (Yeats and others, 1991). Local structures controlling the margin of the basin are not well defined (Beeson and others, 1989; Yeats and others, 1991), except in the southwest corner along the Waldo Hills fault. Structure contours show that the top of the basalt drops off rapidly at the base of the Eola Hills; however,

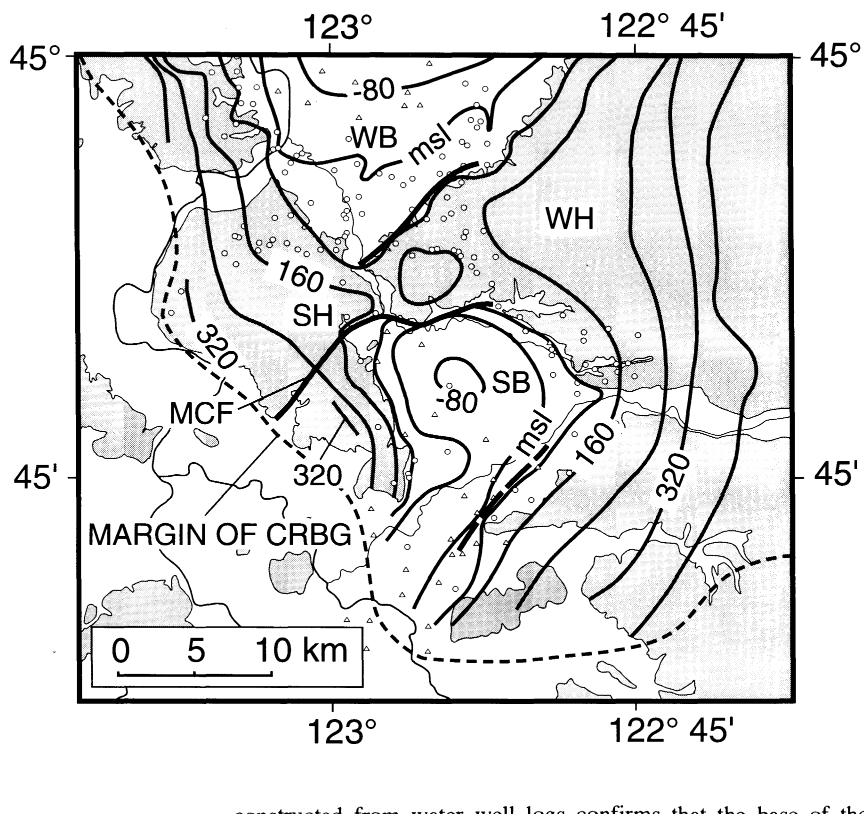


Left:

Figure 8. Geologic cross sections. Heavy long dash indicates inferred fault. Heavy short dash is possible fault extension. Fault dips are unknown. Geology, after Yeats and others (1991), is as follows: Shaded pattern = Columbia River Basalt Group (CRBG); WB = Willamette basin, msl = mean sea level; MOs = marine and nonmarine sedimentary rocks, MOu = strandline sedimentary and volcanic rocks, OEm = marine sedimentary rocks, OEn = volcanic and nonmarine sedimentary rocks. For other abbreviations, see Figures 1 and 2. Section locations are shown in Figure 7.

Below:

Figure 9. Structure contour map of the top of the Columbia River Basalt Group. Open circles = wells penetrating basalt. Open triangles = wells constraining the depth to basalt. Solid lines = faults. Dashed line = inferred fault. Contour interval is 80 m. For symbols and abbreviations, see Figures 1, 7, and 8.



well data are not dense enough to determine whether this boundary is fault controlled (Yeats and others, 1991).

Waldo Hills uplift

The Waldo Hills uplift deforms the Columbia River Basalt Group into a broad, asymmetrical arch following a northeast-southwest trend (Figure 9). This uplift axis crosses the north-south axis of the Willamette Valley synclinorium and imparts a doubly plunging geometry to the structural trough at the core of the synclinorium. At the intersection of the axes, the contrast in deformational polarity is strongest, and the Waldo Hills form a narrow upfaulted block bounded between the Mill Creek and Waldo Hills faults (Figure 8a).

Mill Creek fault

A 16-km-long fault with pronounced vertical displacement transects the Salem Hills at the town of Turner and follows along the southern range front of the Waldo Hills (Figures 7, 9). Previous workers identified this fault as two separate structures, naming it the Turner fault in the Salem Hills and the Mill Creek fault in the Stayton basin (Yeats and others, 1991). The maximum vertical fault displacement of the upper surface of the Columbia River Basalt Group is estimated to be 150 m but may be as much as 210 m (Figure 8a). Given the large vertical offset and short fault length, the dip of the fault plane is probably steep.

Waldo Hills fault

The northern range front of the Waldo Hills forms a prominent, 40-km-long geomorphic lineament following the northeast-southwest structural trend of western Oregon (Wells and Peck, 1961; Yeats and others, 1991; Nakata and others, 1992). A geologic cross section constructed from water well logs confirms that the base of the Columbia River Basalt Group is displaced vertically by at least 90 m at the range front (Figure 8a). Moderately well constrained structure contours reflect vertical offset of both the base and top of the basalt along the southern 7 km of the lineament, but it is uncertain whether the fault continues to the northeast . The linear nature of the range front suggests that the fault plane is steeply dipping, and water wells, shown in cross section, indicate that the fault dips more than 60°, if the dip direction is to the northwest.

TECTONIC AND PALEOGEOGRAPHIC EVOLUTION

Early to middle Miocene (pre-Grande Ronde Basalt)

The area that now forms the northern half of the Willamette Valley was rapidly, perhaps catastrophically, inundated by lava flows of the Grande Ronde Basalt (Beeson and others, 1989). With few exceptions, this influx of lava completely buried a low-relief erosion surface. Hence, paleogeography at the time of burial can be reconstructed from isopach maps and relief on the basal contact of the Grande Ronde Basalt.

Highland areas, characterized by primary flood-basalt thicknesses of 40–80 m, included the Waldo Hills and the Western Cascades (Figure 10). Highlands in the Waldo Hills probably resulted from tectonic uplift on trend with the Scotts Mills anticline, a structure identified from low-angle dips (less than 10°) in Oligocene to early Miocene age strata (Miller and Orr, 1986). Considering the spatial coincidence of these narrow highlands with the location of the range-bounding faults, it is likely that the Waldo Hills uplift was active in the early to middle Miocene. This timing is coeval with folding of the Scotts Mills anticline (Miller and Orr, 1986) and supports linkage of the two structures.

Lowland areas, characterized by primary basalt thicknesses of 80–160 m, included the Stayton basin, the southern Willamette basin, and the Salem-Eola Hills, which now form inverted topography. Discontinuous fingers of basalt, 120 m to 180 m thick, appear to mark a system of preexisting channels connecting these lowlands. Dense well control in the Salem Hills demonstrates 100 m of relief on the basal contact of the basalt west of the ancestral Waldo Hills (see Figure 10). This channel probably extended eastward across the Stayton basin to connect with thick basalt, inferred from structure contours, following the modern channel of the North Santiam River. Four wells, on a north-south transect across the river, define a 4-km-wide channel in sedimentary rock, with at least 30 m of relief on the basal contact of the basalt. An outlier of Grande Ronde Basalt at least 150 m thick (Yeats and others, 1991) lies farther up the river drainage and is a likely extension of this channel. Similarly, a 120-m-thick outlier of Grande Ronde Basalt at Franklin Butte probably marks a smaller tributary channel.

The margin location and the inferred bend in the main lowland channel suggest that Grande Ronde flows abutted against highlands in the southern Willamette Valley that were contiguous with the Salem and Eola Hills. These highlands would have prevented flows from proceeding farther southward and forced backfilling of drainages exiting the Cascades. If this interpretation is correct, these west-flowing drainages were the headwaters of the ancestral Willamette River, and the southern Willamette Valley had not yet formed.

Middle Miocene to Pliocene (post-Grande Ronde Basalt)

Emplacement of the Grande Ronde Basalt forced drainage to the west side of the ancestral Willamette Valley and established a west-flowing channel across the incipient Coast Range; later flows, belonging to the Wanapum Basalt, spilled into paleochannels incised at the margins of the Grande Ronde Basalt and reached the coast (Beeson and others, 1985, 1989; see Figure 8c). Subsequent downwarping of the Willamette Valley synclinorium deflected the ancestral Willamette River towards the central axis of the valley.

Middle Miocene uplift of the Waldo Hills, however, may have blocked a route through the subsiding Stayton basin and deflected the river west of the Salem Hills. The Salem water gap is incised into the Salem-Eola Hills homocline, while the alternate route, the Mill Creek water gap, is incised into the Waldo Hills uplift. Uplift of Columbia River Basalt Group in the Salem and Eola Hills is twice that in the Waldo Hills, 320 m MSL and 160 m MSL, respectively. This suggests that the ancestral Willamette River continuously occupied the Salem gap in order to maintain an incision rate that kept pace with the fastest long-term uplift rate in the study area.

Fault-controlled uplift of the Waldo Hills after emplacement of the Columbia River Basalt Group is indicated by roughly equal amounts of (1) relief (about 90 m) on the upper surface of the basalt and (2) vertical displacement on the lower contact of the basalt across the Waldo Hills fault. This episode of active faulting ended before deposition of the North Santiam gravel fan, the base of which exhibits little or no vertical displacement (see Figure 4). Extensive erosion and degradation of the fault escarpment that forms the northern range front of the Waldo Hills provides a similar constraint on the age of faulting. The sinuosity of fault-controlled range fronts (i.e., measured length of the piedmont-range junction) serves as an index of tectonic activity (Bull and McFadden, 1977). The sinuosity ratio of the northern range front of the Waldo Hills is 1.7, a value characteristic of low fault activity.

In the late Miocene, the Salem-Eola Hills homocline, in concert with the Waldo Hills uplift, formed a continuous belt of uplift extending across the central Willamette Valley. This uplift belt acted as a tectonic dam, obstructing the ancestral Willamette River and causing a thick section of basin-fill sediments to accumulate in

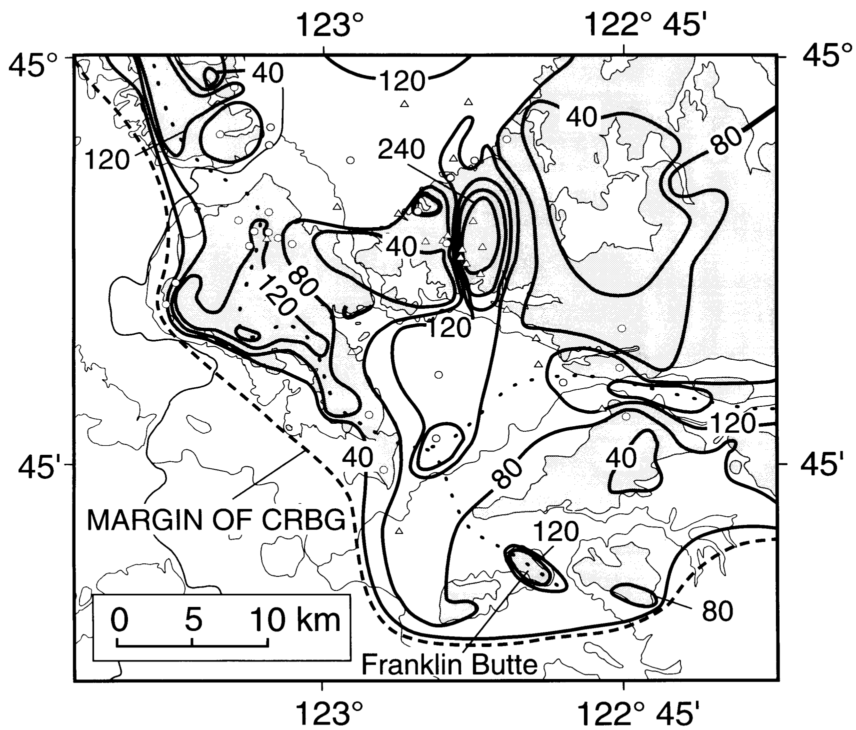


Figure 10. Isopach map showing the restored thickness of the Columbia River Basalt Group. Erosion in drainages less than 4 km wide is restored. Shaded area shows surface exposure of the basalt. Open circles = wells penetrating the base of basalt or older bedrock. Open triangles = wells that do not reach the base of basalt. Dotted lines = inferred drainage channels buried by Grande Ronde Basalt. North-trending area of anomalously thick basalt in Waldo Hills includes subcrop of older basalt. Contour interval is 40 m.

the southern valley. Coeval subsidence of the Stayton and northern Willamette structural basins led to deposition of thick sections of sediments in these basins as well.

Pliocene-Pleistocene

Tectonic subsidence of the northern Willamette basin was synchronous with deposition of fan gravels deposited by the ancestral North Santiam River, while active subsidence of the Stayton basin ceased. In the Stayton basin, the lower boundary of the gravel fan is undeformed, defining an essentially flat-lying interface (Figure 4). North of the Waldo Hills uplift, however, the lower boundary of the gravels inclines into the northern Willamette basin at about 0.1 percent grade. A corresponding increase in gravel thickness from 20 m to 60 m records differential subsidence across the margin of the basin (Figure 2). North of latitude 45°N., these gravels extend into the center of the northern Willamette basin as a series of tectonically inclined layers, reaching depths below –100 m MSL (M. Gannett, written communication, 1993).

The rate of subsidence was probably greater along the southwest margin of the northern Willamette basin, where the gravels thicken most abruptly (Figure 2). Gravels in the Salem water gap fill a bedrock channel that slopes at about 0.8 percent grade, 25 times steeper than the modern channel of the Willamette River. Inclination of this channel records either tectonic tilting and uplift of the Salem-Eola Hills homocline, dip-slip faulting and uplift of the northern Salem and Eola Hills, or burial of a topographic step and falls between the two basins—or a combination of the latter two.

The Sublimity core sediments were deposited in a small drainage immediately adjacent to the head of the North Santiam gravel fan (see Figure 2). Deposition in the drainage was presumably controlled by aggradation of the upper half of the fan, which is laterally equivalent to the core section. If this interpretation is correct, the majority of the gravels in the subsurface are older than 0.78 Ma (middle Pleistocene), and the valley fill aggraded to its present elevation (about 140 m MSL) before the polarity change with which the Brunhes epoch begins. Tectonic changes in the elevation of the core site, since deposition of the cored sediments, are probably small, because (1) the base of the gravel fan is undeformed in the Stayton basin and (2) the core site lies at the boundary between uplift in the Western Cascades and subsidence in the Stayton basin.

Holocene

A broad convexity in the modern profile of the Willamette River suggests that the Salem-Eola Hills homocline is uplifting relative to the northern Willamette basin (Figure 11b). This convexity, which is centered around the city of Salem, closely resembles deformed river profiles in case studies of active uplift zones and flume experiments (Gregory and Schumm, 1987). The alternative hypothesis is differential channel incision due to varying channel lithology.

There are two principal areas where the Willamette River is forced to flow across erosionally resistant bedrock (Figure 11b). At Oregon City, a 10.5-km-long stretch of the river channel is incised into basalt, and the profile forms a single knickpoint, at the downstream edge of the exposure, that is migrating upstream. At the Salem water gap, incision into marine sedimentary rock and basalt along an 11-km-long stretch of channel is inferred from drill hole logs. Another possible lithologic influence is control of the profile by cemented gravels of the Linn fan. However, downgradient steepening of the profile in the northern Willamette basin is more in accordance with tectonic subsidence than with the undeformed constructional surface of an alluvial fan.

The spatial dimensions of the convexity correlate well with the uplift zone of the Salem-Eola Hills homocline and poorly with the bedrock incision into the Salem water gap (Figure 11). The uplift zone, as indicated by elevation of Columbia River Basalt Group above the valley floor, is 15 km wide. The Willamette River crosses this zone between river km 119 and 166, matching the location and width of the convexity (about 50 km). In contrast, the maximum length of the bedrock-lined channel in the Salem water gap is roughly 11 km, only one-fourth the width of the convexity. The highest river gradient associated with the convexity is aligned with the downriver margin of the uplift zone, while drill hole logs show that the margin of the bedrock incision lies 18 km farther upriver (Figure 11).

The evidence considered here is most consistent with a tectonic origin for the broad convexity. However, further study of the Willamette River, its tributaries, and the geomorphic surfaces in the Willamette Valley is needed to evaluate the possibility of active tectonic deformation.

CONCLUSION

The regional structure of the Salem metropolitan area is a broad, north-south trending structural trough that comprises the core of the Willamette Valley synclinorium. Short northeast- and northwest-trending faults subdivide this trough into smaller structural basins, which include the northern Willamette basin and the Stayton basin. These two basins are separated by the Waldo Hills uplift, a fault-bounded block that transects the regional downwarping axis of the Willamette Valley. Miocene uplift of the Waldo Hills is indicated by thinning of the Columbia River Basalt Group and deflection of the Willamette River west of the structural axis of the valley. Uplift of

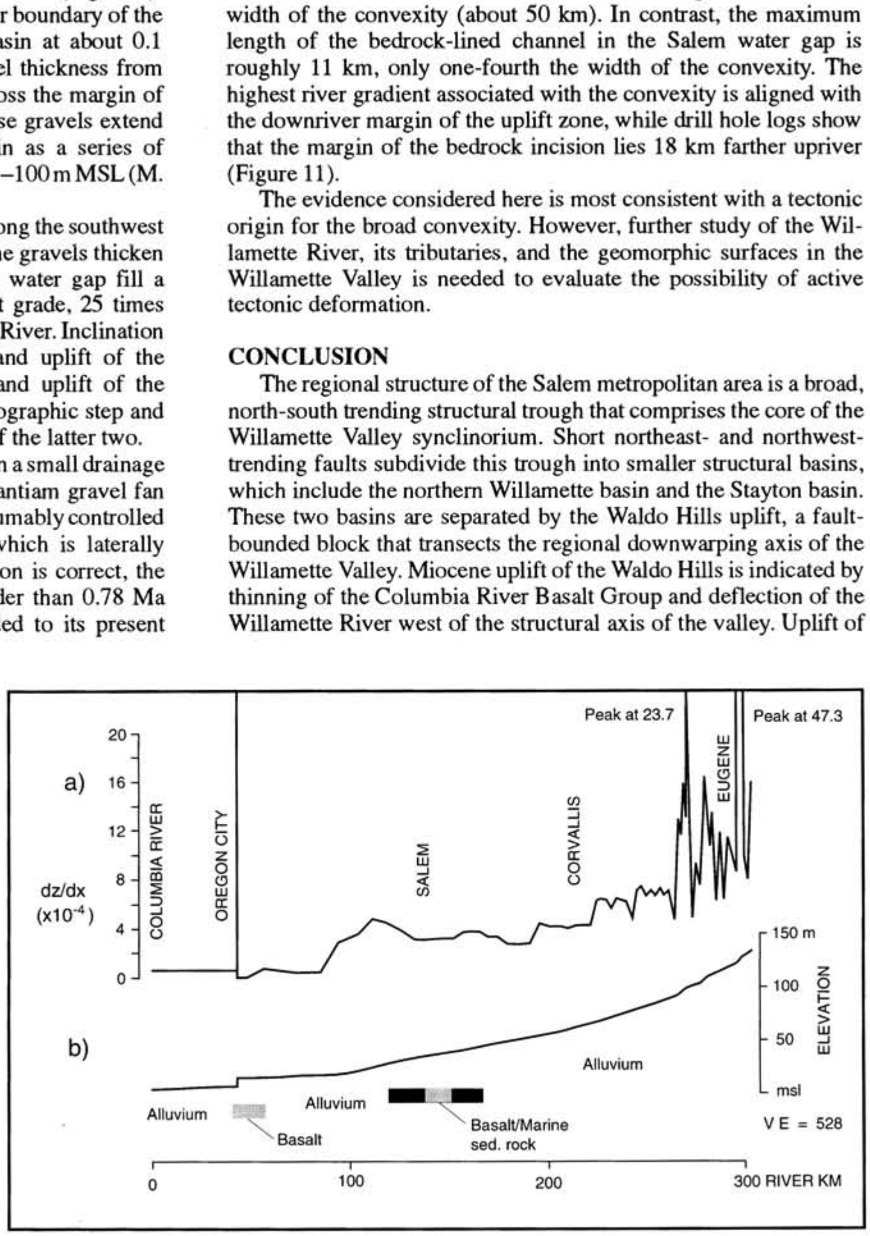


Figure 11. Gradient plot of the Willamette River (a) and longitudinal profile of the Willamette River from its confluence with the Columbia River to the juncture between the Coast Fork and Middle Fork (b). In (a), the broad, low-amplitude increase in gradient north of Salem is associated with a broad convexity in the profile. Spikes near Eugene may be associated with bedrock incisions and/or coarse sediment influxes from the McKenzie River. In (b), the black bar shows uplift zone of the Salem-Eola Hills homocline as defined by elevation of Columbia River Basalt Group above the valley floor. Shaded bar and text indicate geology of the river channel. Both figures are based on Balster and Parsons (1968) between river kilometers 0 and 95 and were constructed from U.S. Geological Survey 7½′ topographic mapping between river kilometers 96 and 301.

the Waldo Hills, in concert with uplift and tilting of the Salem-Eola Hills homocline, formed a tectonic dam that caused a thick section of fine-grained alluvial sediments to accumulate in the southern Willamette Valley.

With the onset of Pliocene-Pleistocene glaciation, a massive alluvial fan associated with the ancestral North Santiam River was deposited in the upper section of the valley fill. These fan gravels traversed the Waldo Hills uplift through a 1-km-wide channel connecting the Stayton and northern Willamette basins. Increasing gravel thickness in the northern Willamette basin indicates that the deposition was synchronous with tectonic subsidence of the basin. Tentative correlation with paleomagnetic and pollen core data suggests that the subsurface gravels are Pliocene to middle Pleistocene.

Holocene uplift of the Salem-Eola Hills homocline relative to the northern Willamette basin is suggested by a broad convexity in the modern longitudinal profile of the Willamette River. Although the long-term rates of vertical deformation are very low, on the order of 10^{-2} mm/year, the magnitude 5.6 oblique-strike-slip earthquake of 1993 near Scotts Mills demonstrated that deformation is continuing.

ACKNOWLEDGMENTS

We thank Marshall Gannett, Scott Burns, Rod Caldwell, Bernard Kleutsch, Cathy Whitlock, Haruo Yamazaki, Alan Niem, and Gordon Grant for providing thoughtful input and aid in acquiring data during this project, and especially Marshall Gannett and Scott Burns for reviewing an early version of this manuscript. The project was supported by the National Earthquake Hazards Reduction Program (Agreement No. 14-08-0001-G2131), and computer facilities were provided by the Geological Survey of Japan.

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THESIS ABSTRACTS

The Department maintains a collection of theses and dissertations on Oregon geology. From time to time, we print abstracts of new acquisitions that in our opinion are of general interest to our readers.

A study and comparison of portions of the Huntington-Olds Ferry and Wallowa-Seven Devils volcanic arc terranes, by Patti M. Goebel (M.S., University of Oregon, 1990), 130 p.

The Clover Creek greenstone of the Wallowa-Seven Devils arc is found to be Permian rather than Triassic as previously believed. The volcanic sequence of the Clover Creek rocks is bimodal, dominated by keratophyre (dacite) flows and tuffs with minor spilite (basalt) flows. This assemblage is representative of immature island-arc or forearc volcanism. The same volcanic assemblage is also found in the other Permian volcanic rocks from both the Wallowa-Seven Devils and Huntington-Olds Ferry terranes. The Clover Creek rocks have undergone low-temperature metamorphism and diagenesis. The main metamorphic assemblages are the zeolite and pumpellyite-prehnite facies, which are representative of burial metamorphism beneath a growing volcanic pile. The Triassic Huntington greenstones of the Huntington-Olds Ferry terrane are characterized by a complete range of volcanic rocks, with andesite being the most abundant. This assemblage is also found in the other Triassic arc rocks of the Wallowa-Seven Devils terrane. The metamorphic/diagenetic assemblage of the Huntington greenstones differs from that of the Clover Creek rocks. Assemblages in the Huntington rocks probably reflect shallow burial or hydrothermal metamorphism as opposed to the somewhat deeper burial metamorphism of the Clover Creek rocks.

Geology and geochemistry of ephithermal gold mineralization in the Lake Owyhee volcanic field-western Snake River Plain region of eastern Oregon and western Idaho, by Brian S. Zimmerman (Ph.D., Washington State University, 1991), 262 p.

The Lake Owyhee volcanic field-Western Snake River Plain region of Oregon and Idaho contains over 30 epithermal gold prospects. Mineralization occurs in a number of diverse geologic settings and hydrothermal environments.

Mineralization on Indian Head Mountain, Idaho, occurs in a lateral fluid flow regime. Fluids moving laterally within a confined aquifer discharged into overlying fault breccias during periods of high fluid flow. Quartz-pyrite veins and breccias are present within the dacite flow which served as the aquifer. Anomalous Au concentration, accompanied by elevated As, Sb, Hg, and Mo concentrations, are found in samples containing abundant pyrite. The overlying fault breccias host quartz-pyrite veins as well as quartz-chlorite/smectite and calcite veins that contain electrum. Mineralization occurred in response to mixing of hydrothermal fluids with cooler groundwaters.

Hydrothermal activity at Red Butte, Oregon, was concurrent with deposition of coarse grained fluvial sediments. This association is typical of epithermal gold prospects in the region. Examples of many of the features of a hot spring Au deposit are exposed on Red Butte, including: siliceous sinter, a blanket of argillic alteration produced by steam-heated waters, and a hydrothermal eruption crater filled with bedded breccia deposits. Electrum is found in quartz-adularia veins below the argillic alteration. Mineralization occurred both in response to fluid boiling and mixing of the boiling fluid with steam-heated waters.

Geochemical comparison of five epithermal gold prospects from the region reveals that, in general, there is more variation within a given prospect than there is among prospects. The Katey and Bannock prospects, which are spatially related to high-silica rhyolite domes, are enriched in Ag, Se, Mo when compared to the other prospects. Mineralization areas containing large amounts of pyrite are enriched in As, Ag, Sb, and Mo.

Potential petroleum reservoir rocks of north-central Oregon, by Alfred J. Riddle (M.S., Loma Linda University, 1990), 240 p.

Petroleum explorationists have commonly assumed, based on the presence of volcanic and/or volcaniclastic rock, that regions such as north-central Oregon do not hold potential as petroleum basins. The typical argument has been that volcanic flows have no effective porosity or permeability and that poorly sorted volcaniclastic sediments contain a high percentage of mineralogically unstable grains that are too easily and rapidly altered into clays and zeolites for any significant or effective porosity to be retained.

The objective of this study was to determine whether potential petroleum reservoir rocks do exist in north-central Oregon. Through field and laboratory study and by comparing this region with petroleum-producing basins with volcanic and volcaniclastic reservoirs, I have determined that the potential volcanic and volcaniclastic reservoirs of this area cannot be entirely "judged" by the "rules" of average siliciclastic reservoirs. Secondary dissolution and fracture porosity are extremely important in these reservoirs and are the natural consequence of hydration reactions, the formation of organic acids during thermal maturation of associated organic-rich source rocks, high geothermal gradients that increase the rate of dissolution of some grains, the flushing of dissolution products out of the reservoirs during diagenesis, and the development of fracture porosity in a tectonically active area. As a result of this study, I have concluded that north-central Oregon does in fact have good potential petroleum reservoir rocks.

Ocean shore protection policy and practices in Oregon: An evaluation of implementation success, by James W. Good (Ph.D., Oregon State University, 1992), 276 p.

Oregon's beaches were designated public recreation areas by the 1967 Beach Law. These beaches and adjacent shorelands experience erosion and other hazards due to winter storm waves, weathering, and geologic instability. Sea cliff recession threatens older development, and inadequate construction setbacks create hazards for new buildings. The typical hazard response is to install a hard shore protection structure (SPS).

An evaluation of shore protection and land use policy implementation, factoring in recent advances in our understanding of coastal processes and engineering, suggests that policies designed to mitigate hazards and protect the beach are not working well.

Five state laws that make up the "shore protection management regime" were examined using an ocean-front, tax-lot-based geographic information system (GIS) for the 16-mile long Siletz littoral cell on the central coast. Policy objectives were determined, measures of achievement and related data needs were identified, and the GIS designed accordingly. Seven principal shore protection policy objectives and 25 measures of achievement were identified. GIS queries related to these measures revealed that 49 percent of the Siletz cell beach front has been hardened with SPSs—69 percent of it since the 1967 Beach Law. Because of jurisdictional gaps, 31 percent of the post-1967 SPSs were not regulated. For those that were regulated and approved, no clear need could be determined in 35 percent of the cases. Also, 28 percent of the SPSs were installed on vacant lots, often because local officials required a SPS before owners could obtain a building permit. This and other findings, such as inadequate construction setbacks, suggest that land use decisions, more than erosion hazards, are driving the demand for beach front SPSs.

In the SPS permit process, alternatives to hard SPSs are not thoroughly evaluated. SPSs are typically over-designed, and many encroach on the public beach, affecting access. Cumulative SPS impacts are significant, especially the blocking of 39 percent of the sand supply from eroding sea cliffs. Given expected future erosion and relative sea level rise along the central Oregon coast, some beaches may gradually disappear.

Based on this analysis, Oregon's ocean shore protection management regime needs an overhaul. Addressing these policy issues now will help preserve Oregon's beaches for future generations.

Geology and geochemistry of a portion of the eastern Clarno Formation, Grant County, Oregon, by Sandra P. Lilligren (M.S., Washington State University, 1992), 155 p.

Two stratigraphic sequences are distinguished within the mid-Tertiary calc-alkaline Clarno Formation in northeast Oregon and have been identified by combining field mapping, geochemical analyses, and petrography.

The lower sequence is dominated by andesite and dacite flows but also contains basalt with relatively high FeO* and TiO_2 concentrations. It is more alkaline than the upper sequence, contains Nb concentrations ranging from 18 to 62 ppm, and is dated at 39.9 to 36.7 Ma. The upper sequence, with ages from 37.6 to 33.6 Ma, is andesite and hornblende-phyric dacite and is overlain by olivine-phyric basalt with high Sr concentrations. Nb concentrations in the upper sequence are <23 ppm. Both sequences are intercalated with voluminous volcaniclastic debris flows. All flows are chemically and physically variable and cover very limited areas. Their relatively primitive isotopic signature (Sr_i = 0.70343 to 0.70370, and Nd_i = 0.512830 to 0.512893) implies an origin from a source or sources not long removed from the convecting asthenosphere.

No simple continuum exists between either of the two sequences or between them and the andesite-dominated western Clarno, where most earlier studies of the Clarno have concentrated. The western Clarno is less alkalic than the eastern, and the three sequences vary in Nb and total alkali contents over a similar SiO_2 range.

It is argued that simple fractionation cannot be the controlling factor in causing chemical variation between and within each of these sequences. Rather, mixing of silicic (crustal) and basaltic (mantle) components is suggested by the petrographic and chemical evidence. Variety in the mantle component could originate from three separate sources or could result from partial melts of variable degree and depth from one source. The Clarno is similar to calc-alkaline assemblages associated with subduction environments along continental margins but is probably a product of regional extension, which permitted the partial melting of both enriched sub-lithospheric mantle and crust created by earlier subduction events during the Mesozoic.

Geology and petrology of a 26-Ma trachybasalt to peralkaline rhyolite suite exposed at Hart Mountain, southern Oregon, by Allyson C. Mathis (M.S., Oregon State University, 1993), 141 p.

Rocks older than the Steens Basalt in southeastern Oregon are mainly exposed in prominent fault scarps such as Steens Mountain, Hart Mountain, and Abert Rim. At Hart Mountain, the section consists of a suite of trachybasalt to trachyte to peralkaline rhyolite lava flows and tuffs. The Hart Mountain volcanic complex contains the only known pantellerites and the oldest peralkaline rhyolites (26.3 Ma) in the Basin and Range province.

$^{40}Ar/^{39}Ar$ age determinations from feldspar separates from a basaltic trachyandesite near the base (26.48 ± 0.13 Ma; one sigma error) and a peralkaline rhyolite near the top (26.33 ± 0.04 Ma) of the exposed suite are analytically indistinguishable. The ages and the paucity of sedimentary rocks within the conformable section indicate that the volcanic rocks were erupted during a short time interval and that they probably represent a single magmatic system. The Hart Mountain trachyandesite suite, with a thickness of as much as 450 m, makes up the lower portion of the section and consists predominantly of basaltic trachyandesite to trachyte lava flows and tuffs. The upper portion of the sequence, the Warner Peak rhyolite, is at least 150 m thick; it includes most of the exposed near-vent rocks of the Hart Mountain volcanic complex east of the field area and is mostly pantellerites and comendites with a few interlayered trachytes.

Major and trace element models demonstrate that crystal fractionation of plagioclase > olivine ≈ clinopyroxene > Fe Ti oxides > apatite from a range of alkali basaltic to trachybasaltic parents can account for the Hart Mountain trachyandesite suite. Textural evidence indicates that some mixing also occurred in the trachyandesitic composition range. Approximately 90 percent crystal fractionation is required to produce trachyte from trachybasalt. Approximately 40-50 percent crystal fractionation of trachytic parents is needed to generate the range of peralkaline rhyolites in the Warner Peak rhyolite. Modeling of the petrogenesis of the Warner Peak rhyolite, however, is qualitative because of compositional changes these peralkaline rocks have undergone with crystallization and/or devitrification.

The Hart Mountain volcanic complex is similar to strongly peralkaline volcanic systems, such as Pantelleria, rather than weakly peralkaline centers (e.g., McDermitt caldera, Kane Spring Wash caldera, etc.) exposed elsewhere in the Basin and Range. As in strongly peralkaline centers, the Hart Mountain volcanic complex contains pantellerites and comendites, does not include subalkaline rhyolites or high-silica rhyolites, and consists predominantly of silicic rocks (~ 85 volume percent). Unlike strongly peralkaline centers, the Hart Mountain volcanic complex does not have a silica gap between the mafic and silicic end members. Also, rhyolites of the Hart Mountain volcanic complex do not have the extreme enrichment of incompatible elements (Rb, Zr, REE) that are characteristic of pantellerites found elsewhere.

The well-documented association of peralkaline rhyolites with extensional environments suggests that south-central Oregon was at least an area of local extension in the late Oligocene. Volcanism elsewhere in the Great Basin at that time consisted of calc-alkaline-alkaline intermediate to silicic magmatism.

Geochemistry, alluvial facies distribution, hydrogeology, and ground-water quality of the Dallas-Monmouth area, Oregon, by Rodney R. Caldwell (M.S., Portland State University, 1993), 198 p.

The Dallas-Monmouth area, located in the west-central Willamette Valley, Oregon, consists of Tertiary marine and volcanic bedrock units that are locally overlain by alluvium. The occurrence of ground water with high salinities has forced many rural residents to use public water supplies. Lithologic descriptions from driller's logs, geochemical (INAA), and X-ray diffraction analyses were used to determine alluvial facies distribution, geochemical and clay mineral distinctions among the units, and possible sediment sources. Driller's log, chemical and isotopic analysis, and specific conductance information from wells and springs were used to study the hydrogeologic characteristics of the aquifers and determine the distribution, characteristics, controlling factors, and origin of the problem ground waters.

Three lithologic units are recognized within the alluvium on the basis of grain-size: (1) a lower fine-grained unit; (2) a coarse-grained unit; and (3) an upper fine-grained unit. As indicated by geochemical data, probable sediment sources include: (1) Cascade Range for the recent river alluvium; (2) Columbia Basin plutonic or metamorphic rocks for the upper fine-grained older alluvium; and (3) Siletz River Volcanics from the west for the coarse-grained sediment of the older alluvium.

The Spencer Formation (unit Ts) is geochemically distinct from the Yamhill Formation (unit Ty) and the undifferentiated Eocene-Oligocene sedimentary rock (unit Toe) with higher Th, Rb, K, and La and lower Fe, Sc, and Co concentrations. The clay mineralogy of unit Ty is predominantly smectite (86 percent), while unit Ts contains a more varied clay suite (kaolinite, 39 percent; smectite, 53 percent; and illite 8 percent). Units Ty and Toe are geochemically similar but are separated stratigraphically by unit Ts. The Siletz River Volcanics are distinct from the marine sedimentary units with higher Fe, Na, Co, Cr, and Sc concentrations. Units Ty and Toe are geochemically similar to volcanic-arc-derived sediments, while unit Ts is similar to more chemically evolved continental-crust material.

Wells that encounter ground water with high salinities (TDS>300 mg/l) (1) obtain water from the marine sedimentary bedrock units or the older alluvium; (2) are completed within zones of relatively low permeability (specific capacities $\leq$ 5 gpm/ft); and (3) are located in relatively low-lying topographic settings. The poor-quality waters occurring under these conditions may be due to the occurrence of mineralized, regional flow system waters. Aquifers of low permeability are less likely to be flushed with recent meteoric water, whereas upland areas and areas with little low-permeability overburden are likely zones of active recharge and flushing with fresh, meteoric water.

The most saline waters sampled have average isotopic values ($\delta D = -6.7‰$ and $\delta O = -1.7‰$) very near to SMOW, while the other waters sampled have isotopic signatures indicative of a local meteoric origin. The Br/Cl ratios of most (10 of 14) of the waters sampled are within 20 percent of sea water. A marine connate origin is proposed for these waters with varying amounts of dilution with meteoric waters and water-rock interaction. The problem waters can be classified into three chemically distinct groups: (1) $CaCl_2$ waters, with Ca as the dominant cation; (2) NaCl waters with Na as the dominant cation; and (3) Na-Ca-Cl waters with nearly equal Na and Ca concentrations. NaCl and $CaCl_2$ waters may have similar marine connate origins but have undergone different evolutionary histories. Na-Ca-Cl waters may represent a mixing of the NaCl and $CaCl_2$ waters.

Late Quaternary crustal deformation on the central Oregon coast as deduced from uplifted wave-cut platforms, by Robert Ticknor (M.S., Western Washington University, 1993), 70 p.

Uplifted wave-cut platforms are used as datum surfaces from which to describe late Quaternary deformation along a 65-km portion of the Oregon coast, between the latitudes of 44.23° and 44.75° N. Within this area, the remnants of six uplifted marine terraces are preserved. Ascending in elevation, they are the Newport, Wakonda, Yachats, Crestview, Fern Ridge, and Alder Grove terraces. Altitudinal surveys, terrace back-edge morphology, cover-bed stratigraphy and soil development were employed as criteria for correlation of platforms. No numerical ages are available for the platforms; however, I estimate the ages of the lowest three by correlation, using soils and amino-acid ratios for fossil shells, to platforms of known age further south on the Oregon coast. The Newport, Wakonda, and Yachats platforms appear to have formed during the 80-, 105-, and 125-ka sea-level high stands. These three lowermost platforms are used to define neotectonic deformation and along-coast trends of uplift rates. In general, platform elevations decrease to the south. The Newport platform (80 ka) is exposed only north of Yaquina Bay, while the Yachats platform (125 ka) is near sea level for the 12-km coastal segment south of Yachats. Late Quaternary faults offset the platforms in two areas. The Yaquina Bay fault trends approximately east-west through Yaquina Bay and has progressively offset the three lowest platforms, down to the south, yielding a vertical slip rate of 0.6 ± 0.06 m/ka. In the vicinity of Alsea Bay, it coincides geographically with the only coseismically buried Holocene marshes on the central Oregon coast, suggesting that the repeated coseismic subsidence events at this site were localized to the downwarp across Alsea Bay and are not necessarily regional in distribution. The uplift rate for the 125-ka terrace decreases to the south, ranging from 0.88 m/ka north of Yaquina Bay to 0.02 m/ka south of Yachats. The latitudinal trend of geodetically derived uplift rates for the past 70 years, in this same coastal reach, is opposite to the trend of uplift rates derived from wave-cut platform elevations. The two trends are coincident at Yaquina Bay, where the Yaquina Bay fault offsets the marine terraces. Given this structural and deformational discontinuity, it is possible that the Yaquina Bay fault coincides geographically with a segment boundary along the Cascadia margin.

Holocene channel changes of Camp Creek; an arroyo in eastern Oregon, by Karin E. Welcher (M.A., University of Oregon, 1993), 145 p.

In the stratigraphic record of Camp Creek are episodes of fluvial scour and fill thousands of years old.

Radiocarbon dates and the Mazama tephra, which serves as a stratigraphic time line, temporally bracket episodes of vertical aggradation and insision. Before 9,000 years B.P., the valley floor was scoured to the Tertiary bedrock. Aggradation dominated since that time. Large cut-and-fill structures indicate that two periods of erosion occurred prior to incision of the modern arroyo. The first occurred before 6,800 yr B.P., and the second occurred approximately 3,000 years ago. The modern arroyo channel flows at or near the Tertiary bedrock is entrenched as much as 9 m in the valley-fill alluvium and is thought to have originated during the late 19th century.

Geology and mineral resources of the Richter Mountain 7.5-minute quadrangle, Douglas and Jackson Counties, Oregon, by Robert B. Murray (M.S., University of Oregon, 1994), 239 p.

The Richter Mountain 7.5-minute quadrangle, in Douglas and Jackson Counties, southwestern Oregon, is approximately bisected by the contact between pre-Tertiary metamorphic and intrusive rocks of the Klamath Mountains geologic province and Tertiary volcanic rocks of the Western Cascades province.

The metamorphic grade of the serpentinites, amphibolites, and metasedimentary rocks that crop out in the western half of the quadrangle grades from epidote amphibolite facies at the northern edge of the quadrangle to amphibolite facies at the southern edge, near Richter Mountain. Metamorphic fabrics are well developed and indicate that at least two prograde events took place, which have been overprinted by a retrograde event. Isograds and fabrics crosscut all lithologic boundaries and are correlative with amphibolites and schists of the May Creek terrane to the south.

All of the metamorphic lithologies are intruded by the 141-Ma White Rock pluton. Preliminary mapping shows that it is crudely zoned inward from biotite trondhjemite to hornblende tonalite, with minor garnet-muscovite-biotite-bearing late-stage granodiorite, granite, and alkali feldspar granite phases.

Tertiary volcanic rocks crop out over all of the eastern half of the quadrangle. The 34.9-Ma Tuff of Bond Creek is a rhyolitic biotite-plagioclase-quartz phyric welded tuff that divides tuffaceous sediments, with minor interbedded tuffs and mafic to silicic flows, into upper and lower units correlative with the Colestin Formation and Little Butte Volcanics, respectively. In the southern half of the quadrangle the Tuff or Mosser Mountain, a plagioclase phyric dacitic welded tuff directly overlies the Tuff of Bond Creek.

Origin of compositional variability of the lavas at Collier Cone, High Cascades, Oregon, by James Daniel Schick (M.S., University of Oregon, 1994), 142 p.

Collier Cone is a Holocene cinder cone located in the High Cascades of Oregon. Over a relatively short period of time, it erupted five distinct units. Included in these units are mafic and silicic xenoliths. These units range in composition from basaltic andesite (55 weight percent SiO_2) to dacite (65 weight percent SiO_2) and have phenocryst contents of <10 to 20 volume percent. The observed variations can be explained as the result of mixing of a basaltic andesite, dacite, and an olivine-plagioclase mafic cumulate. The dacite is best modeled as a combination of silicic xenoliths and a mafic component possibly formed by liquid fractionation. The source of the lavas appears to have been a basaltic andesite magma chamber that was capped by dacite and lined by mafic cumulates in the lower reaches. The results of this study demonstrate the complexity of the processes involved in creating monogenetic volcanoes in subduction zone environments. □

DOGAMI PUBLICATIONS

Released September 30, 1994:

Geologic Map of the Remote Quadrangle, Coos County, Oregon, by Gerald L. Black. Released as map GMS-84 in the DOGAMI Geological Map Series. Price $6.

The Remote quadrangle includes, along its southern edge, the stretch of the Middle Fork Coquille River between Remote and Bridge and extends north as far as Elk Creek, a tributary to the East Fork Coquille River. The quadrangle is at the southwest corner of a block of eight quadrangles for which geologic maps have been already produced or are in progress. Such maps provide basic geologic information about earth resources and geologic hazards that can be used by private citizens as well as local and state government in making well-informed land use and emergency planning decisions.

The two-color geologic map, at a scale of 1:24,000 (1 inch = 2,000 feet), depicts the geology in greater detail than any previous map, identifying 21 rock units and faults and landslides. A geologic cross section is supplied. An eight-page text discusses rock units and geologic history.

Mapping of this quadrangle in the southern Coast Range represents part of DOGAMI's study of the geology of the Tyee sedimentary basin. This study has brought about a considerable amount of new information, which has given geologists a much better understanding of the stratigraphy of the region. The study is supported by a consortium of nine corporations and agencies from private industry and federal, state, and county government and by the National Geologic Mapping Program (STATEMAP) administered by the U.S. Geological Survey.

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Publication title: OREGON GEOLOGY, no. 6000-40; filing date 9-20-94. Published bimonthly, 6 issues per year, annual subscription price $10. Address of publication office, publisher's business office, editor, and owner: 800 NE Oregon St., # 28, Portland, OR 97232-2162. Publisher and owner: Oregon Department of Geology and Mineral Industries. Editor: Klaus K.E. Neuendorf. Managing editor: Beverly F. Vogt, Publications Manager. No bondholders. Circulation during last 12 months / of single issue, respectively: Net press run 3000 / 3000; paid circulation est. 200 / 200; mail subscription 1411 / 1411; total paid circulation 1611 / 1611; free distribution by mail 168 / 169; free distribution outside the mail 199 / 196; total free distribution 367 / 365; total distribution 1978 / 1976; not distributed 1022 / 1024; return 0 / 0; total 3000 / 3000; percent paid and/or requested circulation 81.4 / 81.5. I certify that all information furnished on this form is true and complete.

Klaus K.E. Neuendorf, Editor

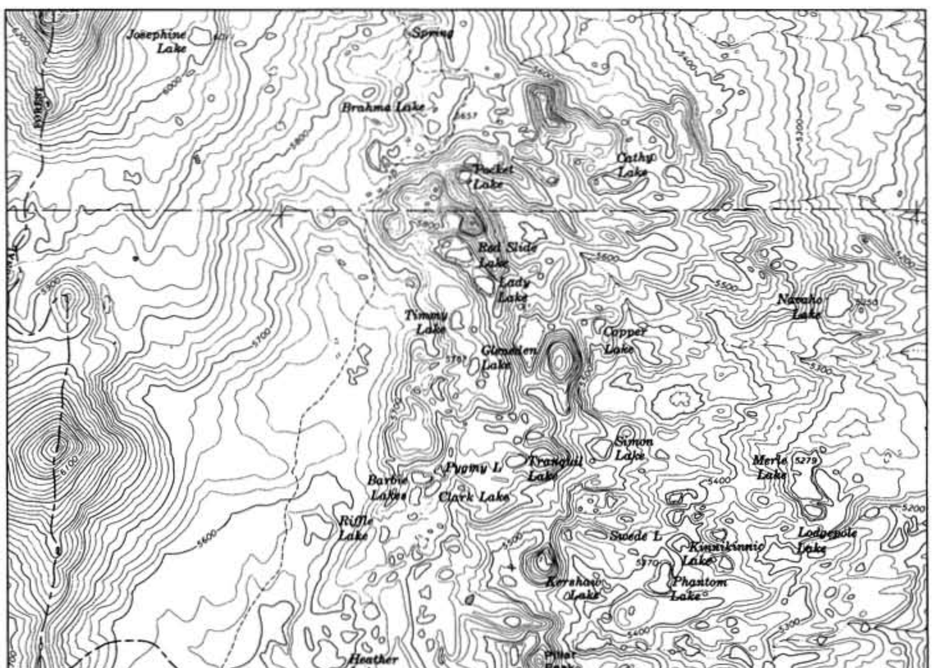
And the winner is . . .

Our photo contest has a winner! Our thanks go to all participants, and we hope it was fun for everybody.

Admittedly, identifying the portion of Oregon shown in the picture was not quite easy, at least the exact identification. Only about 60 percent of the answers were correct. Each participant somehow recognized features typical of the Cascades, but then it took experience with the terrain or thorough map study to locate this lake-studded region. Not many people have had the good fortune to view the Oregon Cascades from the air.

Volcanism and glaciation during the Pleistocene left many lakes of all sizes in several parts of the High Cascades. In fact, one (wrong) guess came as close as the adjacent quadrangle, on the basis that no other area in Oregon had such a lake density. Some participants showed an impressive knowledge of the Cascades. One writer even recognized "the old Forest Service road that winds westerly between the bigger (Irish and Taylor) lakes and eventually (off the picture) ends up at Waldo Lake." Others knew of the South Fork Mackenzie River and the North Fork Willamette River in the valleys on the horizon. The map section below shows the area that makes up the foreground in the photo.

And the winner is—Kyle Gorman of Bend. Congratulations, Kyle! He will donate his prize, the free (two-year) subscription, to the Watermaster's office in Bend.



Central section of Irish Mountain 7½-minute quadrangle, Deschutes and Lane Counties

In memoriam: Bob Bates

Robert Latimer Bates, professor emeritus at Ohio State University, geologist, educator, science writer, and editor, died on June 21 of this year at the age of 82.

Bates wrote *Geology of the Industrial Rocks and Minerals* (1960), which to this day is one of the most important textbooks on the subject. He coauthored *Geology of the Nonmetallics* (1984) and *Industrial Minerals: Geology and World Deposits* (1990, with Peter W. Harben). After his retirement, he took to writing especially for younger people and nonspecialists. He participated in the second and third editions of the *Glossary of Geology* published by the American Geological Institute (AGI). Work for the next edition of the *Glossary* and for a new edition of the U.S. Bureau of Mines *Dictionary of Mining, Mineral, and Related Terms* was underway when he died.

As a specialist in nonmetallic earth materials, Bates regarded his role in founding the Forum on the Geology of Industrial Minerals as his most significant professional accomplishment. After the 25th Forum, which was held in Portland and hosted by the Oregon Department of Geology and Mineral Industries (DOGAMI), he compiled an index to the proceedings of the first 25 meetings that was published by DOGAMI (Special Paper 24, 1990).

"The Geologic Column," is certainly best known to readers of the AGI magazine *Geotimes*—"probably the most widely read of any contribution to the geologic literature," in the words of one of his colleagues. A selection was published in 1986 under the title *Pandora's Bauxite—The Best of Bates* (reviewed in *Oregon Geology* in the June 1987 issue). When he retired from the column in 1987, in his farewell message he confessed: "We have reported no results of research and pushed back no frontiers of knowledge. We have just been interested in having a good time." However, he had developed and maintained the column successfully as a humorous means to promote good writing. Bates combined this concern effectively with his love of the English language. He is often quoted as having said: "It's been said that language is the only natural resource that can be mined indefinitely without depletion. I enjoy mining it." Hugh Hay-Roe, who participates in continuing the *Geologic Column*, concludes his poem "Owed to Robert L. Bates" in that column (September 1994) with the lines: "For 20 years and more you toiled for geowriting free of argot, cant, and jargon soiled: We owe you, R.L.B."☐

Oregon Council of Rock and Mineral Clubs, Inc., 1994 membership list

The Oregon Council of Rock and Mineral Clubs (OCRMC) brings together most rock and mineral clubs in Oregon. It also manages the exhibits in the display case in the State Capitol in Salem, where individual clubs usually take quarterly turns to put up shows. Through the courtesy of the OCRMC, we are able to print the list below. It is alphabetical by city, so that you may more easily find the club you might like to contact in your area.

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B. Jacobs, Secretary, 231-7500

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15006 S Redland Road, **Oregon City**, OR 97045
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PO Box 10682, **Eugene**, OR 97440

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Box 1122, **Hermiston**, OR 97838

North Lincoln Agate Society
PO Box 901, **Lincoln City**, OR 97367-0901

Oregon Trail Gem and Mineral Society
PO Box 274, **Pendleton**, OR 97801 ☐

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