

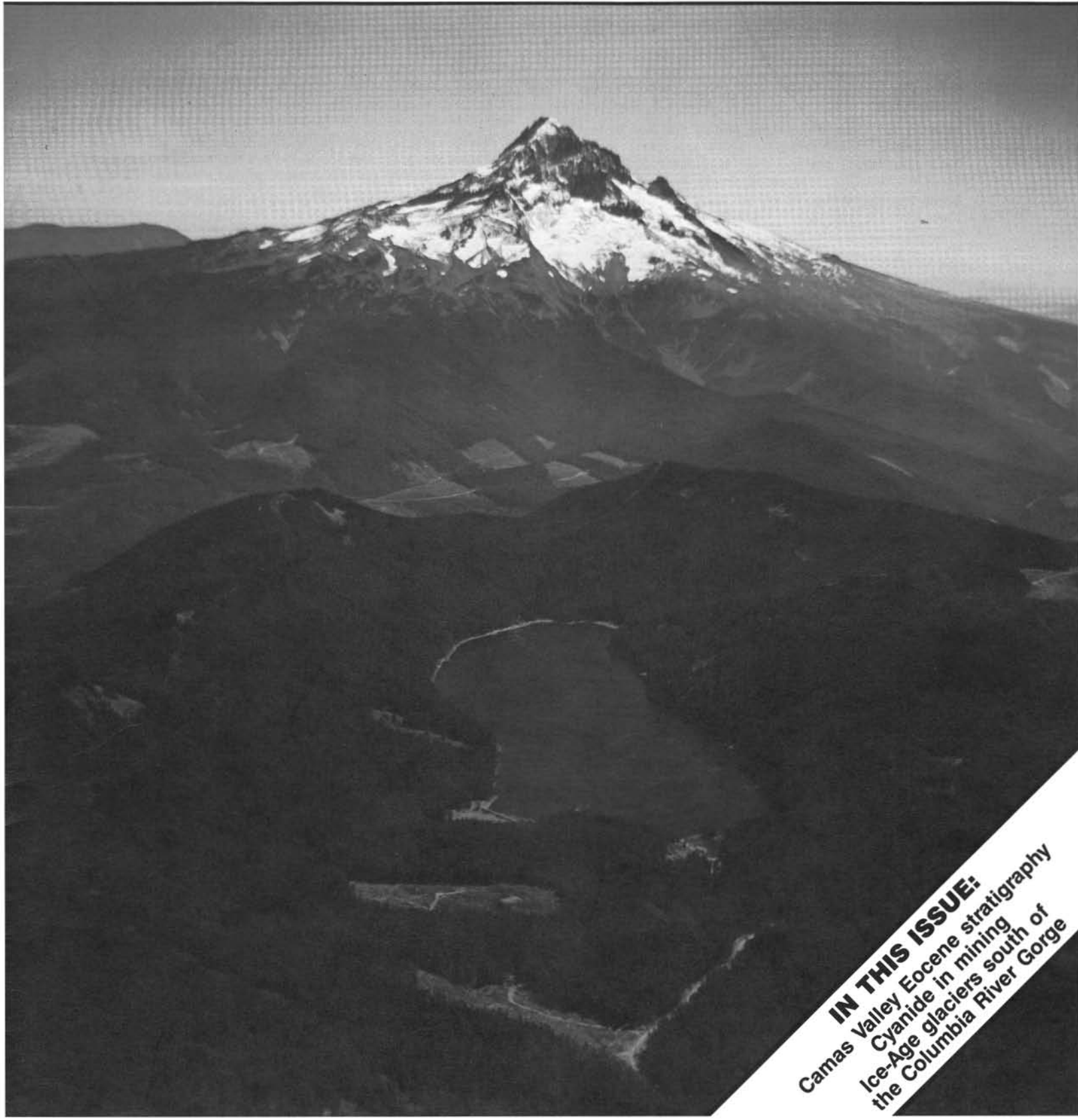
# OREGON GEOLOGY

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**IN THIS ISSUE:**  
Camas Valley Eocene stratigraphy  
Cyanide in mining  
Ice-Age glaciers south of  
the Columbia River Gorge

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The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors*, 6th ed., 1978). 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 DOGAMI.

## COVER PHOTO

Bull Run Lake, in the Bull Run watershed, major water supply for the City of Portland, is located northwest of Mount Hood in Clackamas County. It is one of the geomorphic features of the area that were at least partially formed by glaciers covering the mountain during the Pleistocene (Ice Age). Article beginning on page 12 discusses evidence of past glaciers and lakes south of the Columbia River Gorge.

## OIL AND GAS NEWS

### ARCO finishes 1988 drilling program at Mist

ARCO has completed a successful drilling program at Mist Gas Field, Columbia County. Of the twelve wells drilled to the productive Clark and Wilson sandstone during 1988, seven were completed as producers and five were dry holes. The successful gas wells are the CFI 34-1-55, CFW 12-15-64, CC 12-19-65, CC 24-9-64, CC 42-8-54, CC 44-27-65, and the LF 32-20-65R-RD1. The dry holes are the Benson 14-7-64, CFI 23-16-64, Johnston 44-19-65, LF 24-8-75 and RD1, and the Sterling 12-24-66 and RD1. No rates for the completed gas producers have been released.

Of particular significance is the fact that the locations of several of the gas producers extend the productive area of the Mist Gas Field. The CFW 12-15-64 and CC 24-9-64 are the easternmost gas wells in the field, and extend production 4 mi to the east of any previous producing gas wells. The CC 12-19-65 is the westernmost well in the field, extending gas production to within a quarter of a mile of the border to Clatsop County.

### Clatsop County wildcat wells permitted

ARCO has received permits to drill in Clatsop County, about 12 mi northwest of Mist Gas Field. The permits are for the OR 13-33-86 and OR 21-33-86 wells located in T. 8 N., R. 6 W., and the wells are proposed for a 6,000-ft total depth. Wells drilled previously in this general area have had gas shows, but so far none have been completed as producers.

### NWPA schedules field symposium

The Northwest Petroleum Association will hold its 1989 annual spring field symposium in Spokane, Washington, May 18-19, 1989. The symposium will concentrate on the geology of the Columbia River Basin, Washington. For details, contact Phil Brogan (503-382-0560), or Barbara Portwood (503-287-2762), or write the NWPA, P.O. Box 6679, Portland, OR 97228-6679.

### Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
418	ARCO OR 21-33-86 36-007-00020	NW¼ sec. 33 T. 8 N., R. 6 W. Clatsop County	Location; 6,000.
419	ARCO OR 13-33-86 36-007-00021	SW¼ sec. 33 T. 8 N., R. 6 W. Clatsop County	Location; 6,000. □

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# Eocene unconformities in the Camas Valley quadrangle, Oregon

by Ewart M. Baldwin, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403, and Rauno K. Perttu, CMA, Inc., 2816 Upper Applegate Road, Jacksonville, Oregon 97530

The Oregon Department of Geology and Mineral Industries is initiating a jointly funded, cooperative investigation of the natural-gas potential of the southern Coast Range. Recognition of appropriate stratigraphic interpretations and depositional models for various parts of the study area constitutes a critical dimension of the investigation. The publication of this interpretation of the Eocene stratigraphy of the Camas Valley quadrangle is a valuable contribution to this effort.  
—Editor

## ABSTRACT

Near the end of the early Eocene, a thick section of Paleocene and lower Eocene oceanic basalt of the lower Roseburg Formation and a thick section of flyschlike sandstone and siltstone of the upper Roseburg Formation were shoved against the southern Oregon continental mass. During emplacement, the lower Tertiary section moved in what now is seen as an eastward direction along the Canyonville fault zone relative to the Klamath Mesozoic rocks to the south. Clockwise rotation must be considered in reconstructing original motions.

Accompanying uplift and erosion of the deformed Roseburg and Mesozoic rocks was the unconformable deposition of a blanket of conglomeratic rock from the denuded Klamath terrane upon truncated Roseburg strata. Deposition of this unit, the Bushnell Rock Member of the Lookingglass Formation, which is notably thicker nearer to the Klamath mass and which thins noticeably north of the Canyonville fault zone, was followed by deposition of the thinner sandstone and siltstone of the Tenmile Member, which, in turn, was followed by deposition of the coarser, offlapping Olalla Creek Member. Mild deformation followed as the Lookingglass Formation was eroded from the top of the Porter Creek anticline, and then the onlapping seas deposited the basal sandstone of the White Tail Ridge Member of the Flourney Formation, which trends southward through Camas Mountain and around the south end of Camas Valley. The thinner bedded siltstone of the Camas Valley Member of the Flourney Formation underlies the broader portions of Flourney and Camas Valleys.

The Tyee Formation, a massively bedded, thick sandstone unit, was deposited in the center of the Coast Range following regional warping and rests on all the older Tertiary units. The Tyee Formation is the oldest Tertiary unit to cover the Canyonville fault zone without noticeable offset.

The Paleogene section may be separated into mappable units by unconformities caused by recurring periods of deformation.

## INTRODUCTION

The Eocene stratigraphy of the Camas Valley quadrangle (Figure 1) and nearby parts of Oregon was initially described by Diller (1898). Baldwin (1974) subdivided Diller's Umpqua Formation into the Roseburg, Lookingglass, and Flourney Formations and mapped their regional distribution. The Tyee Formation remained the same as described by Diller, but younger formations to the north were described and named the Elkton Siltstone and the Bateman Formation. Nearly all of the formations formerly in the Umpqua Formation have been divided by Baldwin into members, many of them named for features within the Camas Valley quadrangle. Detailed mapping of these members by Baldwin was critical to determining the structural relationships and boundaries of the geologic formations in the region. The map in this paper (Figure 2) is the first

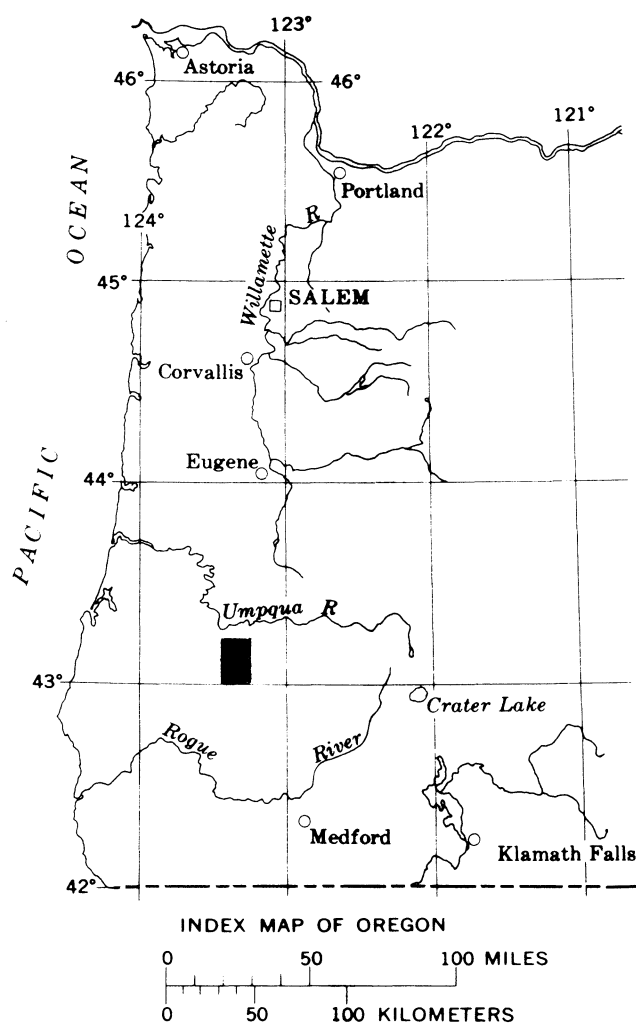


Figure 1. Location of Camas Valley quadrangle, Oregon.

published map showing the areal extent and distribution of the individual members.

Baldwin's study of the Camas Valley quadrangle (Figure 1) began with supervision of graduate studies by N.V. Peterson (1957), who mapped the southeast third of the quadrangle. Baldwin later conducted geologic mapping in the central part of the Oregon Coast Range for the U.S. Geological Survey (USGS), under the supervision of P.D. Snively, Jr., and extended this mapping into the Camas

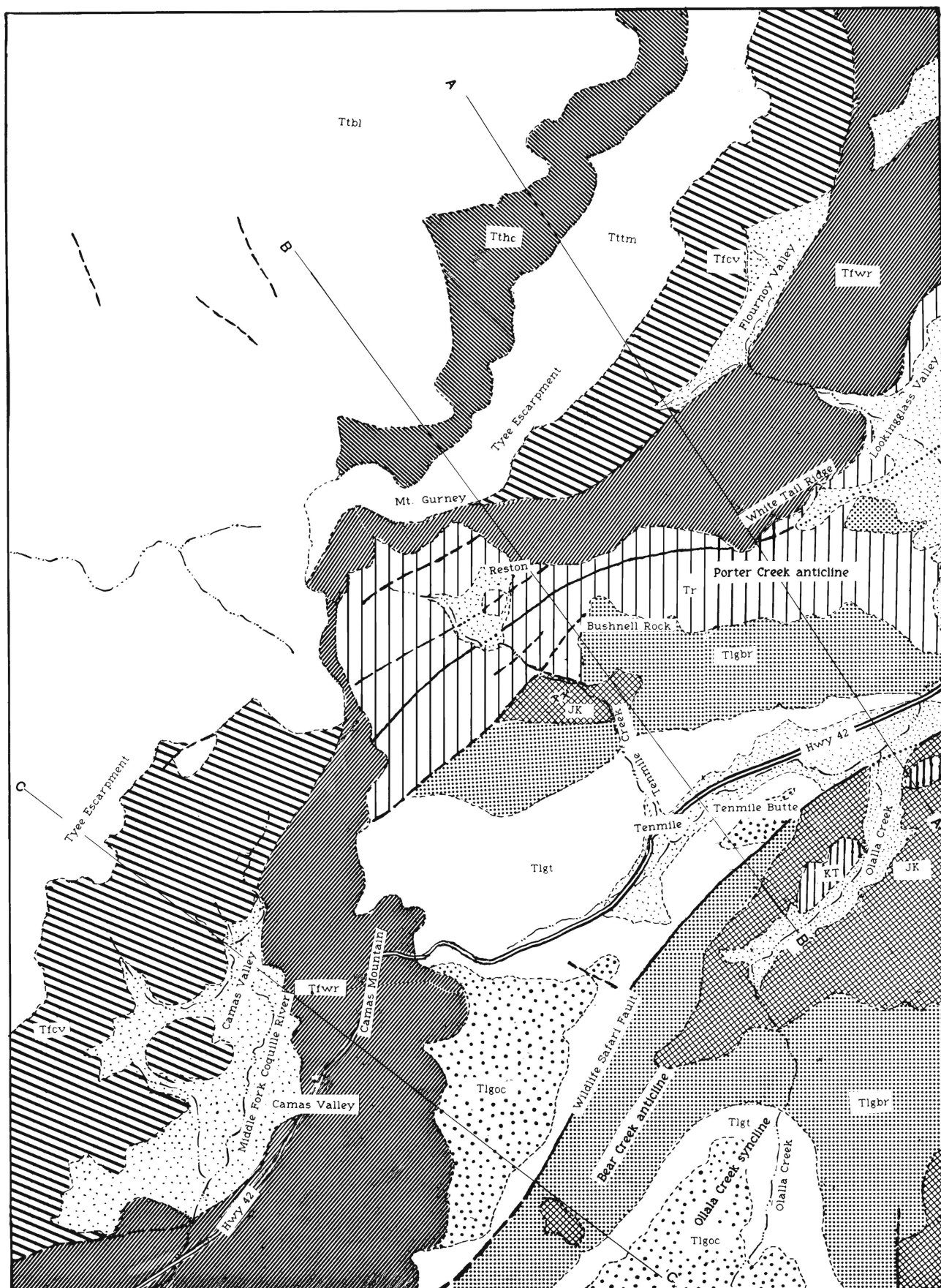


Figure 2. Geologic map of the Camas Valley quadrangle, Oregon. See Figure 3 for map explanation and cross sections.

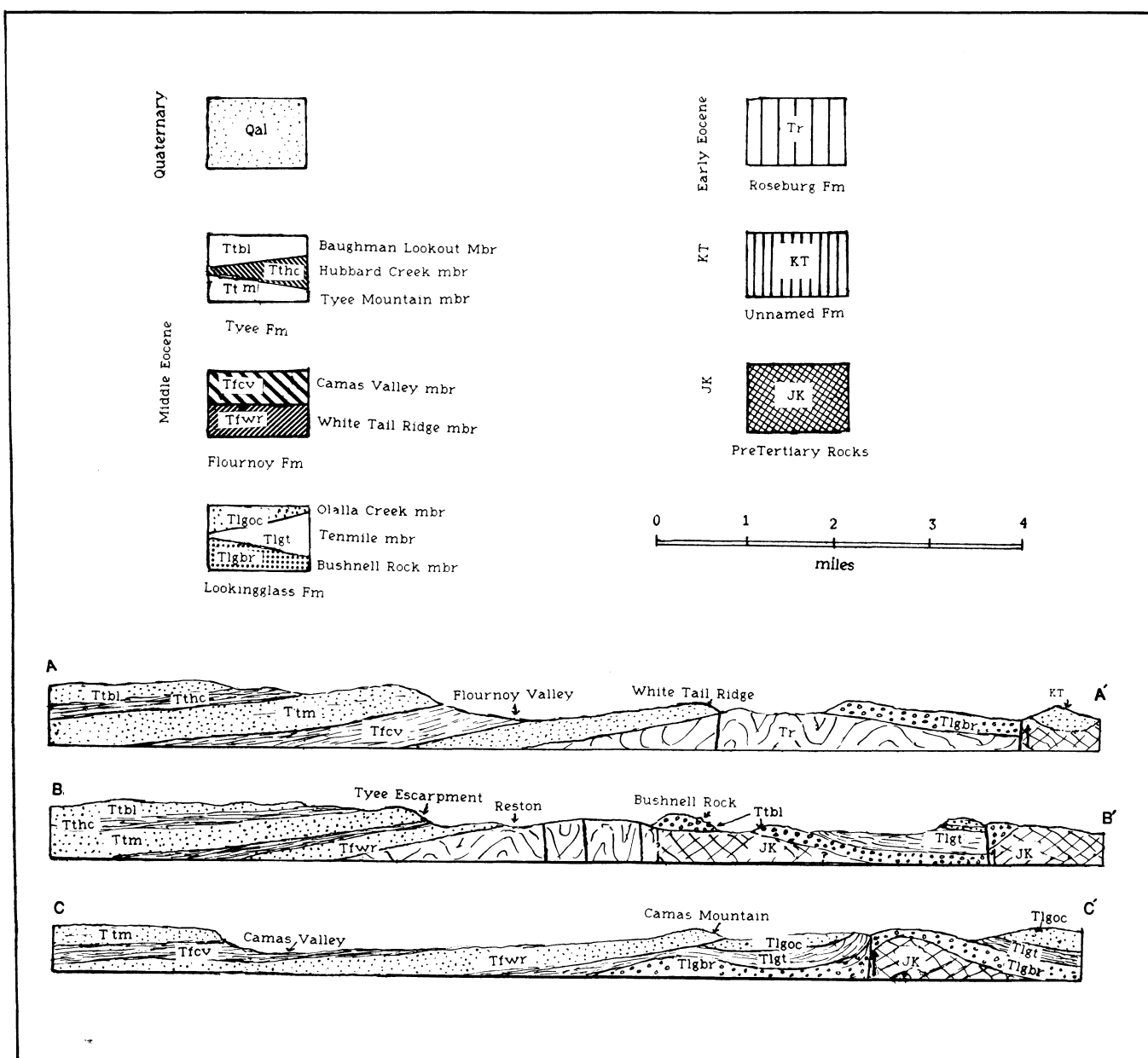


Figure 3. Cross sections and explanation of map symbols for geologic map of the Camas Valley quadrangle (Figure 2).

Valley and Tyee quadrangles in the mid-1960's. When the study of the oil and gas potential of this region was discontinued by the USGS, mapping was sponsored by the Oregon Department of Geology and Mineral Industries (DOGAMI) under H.M. Dole and R.E. Corcoran.

The Camas Valley quadrangle (Figures 2, 3, and 4) is situated near the northern boundary of the Klamath Mountains, which are believed to be an accumulation of accreted miniplates of pre-Tertiary age (Blake and others, 1985). Although there are local complications, Mesozoic rocks in the Camas Valley quadrangle are generally separated from the Tertiary section to the north by the Canyonville fault zone (Perttu, 1976; Baldwin and Perttu, 1980). The Wildlife Safari fault is a northeast-trending branch of the Canyonville fault zone.

## STRATIGRAPHY

No attempt is made herein to subdivide the Mesozoic rocks in the Camas Valley quadrangle. The Mesozoic units have been

discussed by Blake and others (1985). Most of the pre-Tertiary rocks are restricted to the southern end of the quadrangle south of the Wildlife Safari fault. A thick Eocene section occurs north of the fault. One formation of intermediate and as yet undetermined age, sometimes called the "Hoover Hill beds," occurs south of the Wildlife Safari fault and overlies Mesozoic units. We refer to this formation as the "unnamed formation."

## Unnamed formation

Peterson (1957) described beds of uncertain age that crop out in Hoover Hill and Olalla Creek and in a hill just northeast of the Umpqua River bridge east of Winston. Rock of this formation is massively bedded, light-gray, arkosic, coarse- to medium-grained sandstone. The formation is poorly bedded, with only minor siltstone interbeds. Peterson noted that the unnamed unit had an unconformable relationship with the underlying Mesozoic rocks and suggested that it was Late Cretaceous in age, possibly the same age as the Chico (Hornbrook) Formation. We have not found the unnamed forma-

tion and the Roseburg Formation in contact anywhere. Furthermore, the base of the Roseburg Formation is not exposed, because the Roseburg basalt is probably an emplaced seamount or island-arc terrane, so the age relationships of the Roseburg Formation and the unnamed formation are difficult to determine. The unnamed unit is resting on Klamath Mountains terrane and therefore had a different provenance than the Roseburg sediments. It also would not have been subjected to subduction zone jamming and rebound as was the Roseburg Formation (Perttu, 1976). Consequently, even if it were an age equivalent of the Roseburg units, it would appear quite different. Baldwin believes the formation to be of Late Cretaceous or Paleocene age but has found no fossil evidence to confirm this age.

### Roseburg Formation

The Roseburg Formation (Baldwin, 1974) is made up of a thick basal sequence of pillow basalt flows and breccia with minor sandstone interbeds, overlain by a thick section of tuffaceous sedimentary rock. The basalt appears to be thickest in excellent exposures along the North Fork of the Umpqua River from a point about 2 mi west of Glide nearly to Roseburg. The Roseburg Formation also crops out along U.S. Highway I-5 for approximately 35 mi from Scott Valley near Yoncalla to a point south of Roseburg.

In the Camas Valley quadrangle, the formation is mostly well-bedded sandstone and siltstone, which intertongues with lesser amounts of pillow basalt flows. Basalt of the Roseburg Formation is present in the valley of Porter Creek and southwest of Bushnell Rock. The basalt could with considerable effort be mapped as a separate formation and potentially be correlated with the Siletz River Volcanics in the central Coast Range of Oregon and the Crescent Formation in Washington.

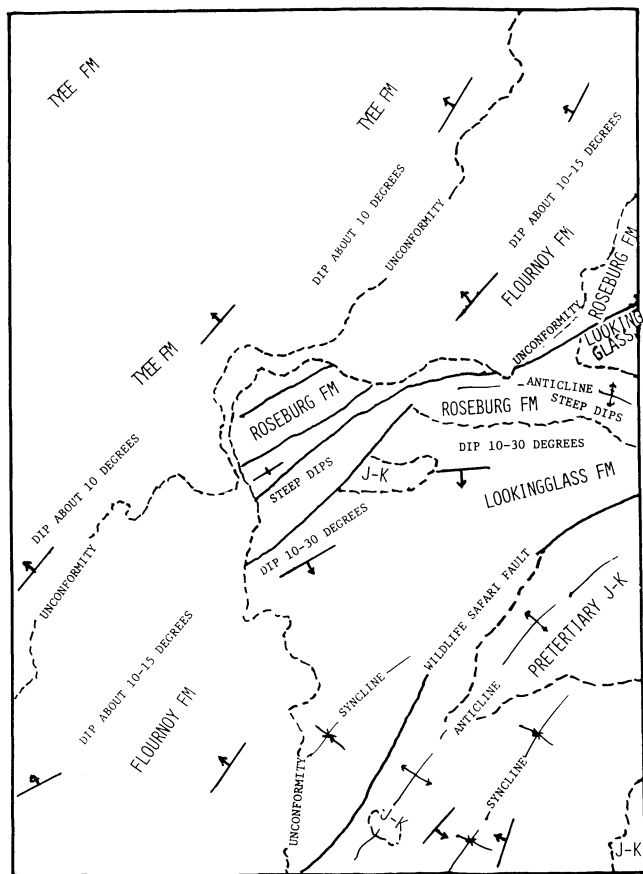


Figure 4. Sketch map showing structural relationships of the formations in the Camas Valley quadrangle.

The complex intertonguing of the Roseburg sedimentary rocks and the top of the basalt makes mapping of the basalt-sediment boundary difficult. Baldwin therefore prefers to retain the units in one formation and considers the basalt the lower member of the formation. If the basalt and sedimentary units of the Roseburg Formation are divided into two formations, then Perttu believes that a second division within the Roseburg sedimentary units would also be appropriate but difficult to make. He believes that the Roseburg sedimentary units must have an underlying, although at least partially age-equivalent, lower member that was deposited in association with the marine basalt volcanic centers and an overlying member that represents continent-derived lower slope and trench flysch that was deposited at the time of emplacement of the Roseburg volcanic piles. At the time of emplacement of the Roseburg volcanic piles and associated sediments into the subduction zone, continent-derived flysch would have partially buried the impinging Roseburg units. Perttu feels that some of the upper Roseburg sediments below the Bushnell Rock Member of the Lookingglass Formation represent such onlap units. These units would be very similar in appearance to the underlying Roseburg flysch but should show a very different provenance.

Bukry and Snively (1988) cite K-Ar dates of 62.1-59.2 million years for five samples of oceanic tholeiitic basalt collected from rock the writers assign to the lower part of the Roseburg Formation. They also found a coccolith assemblage that, like the basalts, ranges from Paleocene into the early Eocene.

Miles (1977) examined the planktonic Foraminifera of the Roseburg, Lookingglass, and Flournoy Formations. He found that the Foraminifera of the Roseburg and Lookingglass Formations are indistinguishable. He assigned the units to the P7 and P8 zones of the "standard" tropical zonation. He found none that he could definitely assign to the Paleocene. It is possible that the foraminiferal and coccolith zonations are not quite the same.

The Roseburg beds were steeply folded and faulted during the latter stages of continental accretion when the Roseburg Formation moved eastward relative to the Klamath terrane. This deformation probably accompanied emplacement of the Roseburg Formation volcanics and associated sediments against the North American continent during possible jamming and subsequent westward jumping of an Eocene subduction zone.

Faults and folds of the Roseburg Formation trend N. 50°-80° E. (Baldwin, 1964; Perttu and Benson, 1980). This trend may represent a later clockwise rotation of structures that originally paralleled the continental margin. When the movement along the Canyonville fault zone before rotation is considered, the implied original direction of impingement of the Roseburg Formation against the continent was at an angle of approximately N. 10° E.

### Lookingglass Formation

The Lookingglass Formation (Baldwin, 1974) was named for exposures of the formation along Lookingglass Creek in Lookingglass Valley. The formation has been divided into the lower conglomeratic Bushnell Rock Member, the middle Tenmile Member, and the upper Olalla Creek Member. The Lookingglass Formation may represent sediments that were deposited immediately after the collision of the Roseburg block with the subduction zone.

The Bushnell Rock Member is a massive conglomerate nearly 800 ft thick that rests on both steeply dipping Roseburg strata and pre-Tertiary rocks along Tenmile Creek (Figure 2). The conglomerate rests directly on the eroded surface of the Klamath terrane south of the Wildlife Safari fault. Movement along the fault appears to have been right-lateral through Roseburg time. Perttu suggests that movement along the Canyonville fault system, of which the Wildlife Safari fault is a strand, is more than 40 km. Immediately after jamming of the subduction zone, right-lateral movement on the Canyonville fault system would have ended, and rebounding of the inactivated subduction zone would have occurred. This rebounding,

which was initially accompanied by continued compressive deformation, resulted in rapid erosion, generating the Bushnell Rock conglomerates. The conglomerate thins rapidly to the north. The entire Lookingglass Formation does not crop out north of a line drawn from Coos Bay to Sutherlin. Flournoy beds surround Roseburg basalt outcrops in the Coos Bay and Drain quadrangles without the presence of the intervening Lookingglass clastic wedge.

The Tenmile Member is composed of nearly 5,000 ft of thinly bedded sandstone and siltstone beds in the valley of Tenmile Creek. Microfossils from this member have been dated by Miles (1977) as early Eocene.

The Olalla Creek Member is dominantly conglomerate and is similar to the Bushnell Rock Member. It also represents rapid erosion of the Klamath Mountains terrane following renewal of uplift along the south side of the Canyonville fault zone. This uplift may have been associated with the formation of a new wedge of underthrust sediments below the new continental margin along the new subduction zone to the west and development of new drainage systems across the newly accreted terrane. The Olalla Creek Member is thickest in the Olalla Creek syncline, which was active during deposition of the member. A small patch of the member also caps Tenmile Butte. Some of the beds are red, perhaps indicating oxidation on subaerial fan surfaces.

### Flournoy Formation

The Flournoy Formation (Figure 5) is named for outcrops of the formation's basal sandstone in White Tail Ridge and siltstone in Flournoy Valley. The White Tail Ridge Member sandstone thins around the western end of the Porter Creek anticline and extends to Camas Mountain; then the beds curve westward around the south end of Camas Valley, forming a gentle dip slope under the valley. The sandstone is not as well graded in Camas Valley as it is farther to the north and west in the Coast Range. The beds in White Tail Ridge were deposited in shallower water near the shore.

The upper thinly bedded sandstone and siltstone of the Flournoy Formation crop out in the Flournoy and Camas Valleys. This unit was named the Camas Valley Member for exposures in Camas Valley and up the side of the nearby Tyee escarpment. Baldwin (1974) correlated the Sacchi Beach Beds and the Lorane Siltstone with the Camas Valley Member of the Flournoy Formation. Microfossils in the Camas Valley Member are middle Eocene (Ulatisian) in age (Miles, 1977).

### Tyee Formation

The Tyee Formation was named first when Diller (1898) called it "Tyee sandstone." Although no type section was designated, the name was taken from Tyee Mountain, which is located north of Coles Valley. The Umpqua River enters a canyon it has carved into the sandstone beds of the Tyee Formation. Details concerning the lithology and mode of deposition of the formation are discussed by Chan and Dott (1983) and by Heller and Ryberg (1983). Baldwin divided the Tyee Formation along its eastern margin into the Tyee Mountain Member, the Hubbard Creek Member, and the Baughman Lookout Member. The lower and upper members are composed of thickly bedded sandstone with thin layers of siltstone. Pebbles are remarkably scarce. The Tyee Mountain Member sandstone, which is 2,500 ft thick in Tyee Mountain, can be traced southward along the Tyee escarpment, where it unconformably overlies the Camas Valley Member of the Flournoy Formation. South of Mount Gurney, the beds appear to thin and pinch out against the Porter Creek anticline. This relationship may imply that the anticline was a positive area still undergoing some compression at the time of Tyee deposition.

The Hubbard Creek Member, which consists of about 400 ft of thinly bedded sandstone and siltstone beds, crops out along Hubbard Creek in the Tyee quadrangle to the north. This member pinches out south of Mount Gurney.

The Baughman Lookout Member of the Tyee Formation forms much of the southern Coast Range. It continues southward into the Bone Mountain and Eden Ridge quadrangles. Like the Tyee Mountain Member, the Baughman Lookout Member is massively bedded and approximately 2,500 ft thick. This member may interfinger with the Elkton Siltstone to the north. The Tyee Formation appears to be disconformable on older units in the Camas Valley quadrangle. On the western edge of the Coast Range syncline, the Camas Valley silty beds were eroded, leaving the basal Tyee sandstone resting on the White Tail Ridge Member sandstone of the Flournoy Formation. The two formations are very similar in appearance. In other locations, such as along the uppermost portion of the North Fork of the Coquille River and just west of Sitkum, the Tyee Formation rests on the Camas Valley siltstone. The contact is relatively easy to determine in these areas. The Tyee Formation overlaps all older Eocene units in the southern Coast Range and thus demonstrates its unconformable relationship with these older units. The Tyee Formation is the oldest Eocene formation to bridge the Canyonville fault zone without noticeable offset. Fossils as well as stratigraphic position indicate a middle Eocene age for the Tyee Formation. The formation appears to represent a major delta system that developed from the (now) southeast and unconformably overlapped the older formations and structures of the continental shelf and slope. The Tyee Formation is locally nonmarine in its southern exposures, where it contains coal seams, and becomes progressively deeper water marine to the north.



Figure 5. Flournoy Valley from Mount Gurney.

### Younger Eocene formations

No younger Eocene formations crop out in the Camas Valley quadrangle. The upper part of the Tyee Formation interfingers with the Elkton Siltstone in the Elkton quadrangle, and it is in turn overlain in the southern part of the Elkton quadrangle by shallow water to nonmarine coal-bearing, deltaic beds of the Bateman Formation (Baldwin, 1961). To the west, the Coos Bay syncline contains 6,000 ft of deltaic, coal-bearing strata of the Coaledo Formation. This formation rests unconformably on the Roseburg, Lookingglass, and Flournoy Formations. The Coaledo Formation is nowhere in contact with the Tyee, Elkton, or Bateman Formations. Beds called Elkton by some writers at and south of Cape Arago are considered by Baldwin to be upper Flournoy siltstone. The Bastendorff and Tunnel Point Formations of latest Eocene age rest with apparent conformity upon the Coaledo Formation. The Coaledo Formation probably represents a deltaic system that was independent of the Tyee system. It is spatially associated with the Coos Bay syncline,



which was actively deforming during Coaledo time, and appears to have periodically continued downwarping to the present. The downwarping may have been associated with lateral faulting, which may have shifted the Coaledo block northward relative to the other formations to the east.

## DISCUSSION OF STRATIGRAPHIC USAGE

The International Subcommission on Stratigraphic Classification (ISSC) has discussed stratigraphic units such as the Roseburg, Lookingglass, and Flourney Formations that are unconformity bounded (ISSC, 1987). The magnitude and extent of the unconformity help define the terminology. Although the term "sequence" has been used for such units, the term has not been used consistently. The subcommission proposed the name "synthem" to replace "sequence."

Baldwin's three subdivisions of Diller's Umpqua Formation are unconformity bounded throughout all of the southern Coast Range. The post-Roseburg unconformity represents erosion that accompanied severe folding and thrusting that occurred during final emplacement of the Roseburg Formation against the continental coastline. Baldwin and Lent (1972) proposed that the Colebrooke Schist in the northern Klamath Range was emplaced at the same time as the Roseburg Formation was deformed. That part of the Klamath terrane that crops out along Tenmile Creek south of Bushnell Rock may have been thrust to its present position at the same time. Baldwin believes that the pre-Tertiary units along Tenmile Creek may have come from a position south of the Canyonville fault zone.

If the terminology proposed by the ISSC is adopted, then the Roseburg, Lookingglass, and Flourney Formations might qualify as synthems. The Lookingglass "synthem" could be divided into the Bushnell Rock, Tenmile, and Olalla Creek "Formations." If there were minor unconformities separating them, which we have not found, they would be "subsynthems." The ISSC says (ISSC, 1987, p. 234):

"Unconformity-bounded units should not be used when they are not necessary, and only those that serve a useful purpose should be recognized. Unconformity-bounded units should be established only where and when they can fulfill a need that other kinds of stratigraphic units cannot meet, where they can contribute to the understanding of the stratigraphy and geologic history of an area..."

We do not intend to formally change the terminology of the Eocene units in the southern Oregon Coast Range. Nevertheless, the importance of the regional unconformities in deciphering the history and stratigraphy of the area should not be overlooked.

The Roseburg, Lookingglass, and Flourney Formations are subdivisions of Diller's Umpqua Formation. Some have referred to these formations as the "Umpqua Group." From a historical standpoint, this may be appropriate. The definition of a group is "the lithologic unit next higher in rank than a formation." Groups are defined to express the natural relationships of associated formations. It is possible that such profound unconformities within the "Umpqua Group" would make the use of the word inappropriate. However, if the Roseburg, Lookingglass, and Flourney Formations may be questionably of group rank, there should be little doubt that they can no longer be lumped together as the Umpqua Formation. Molenaar (1985), however, rejected the Roseburg, Lookingglass, and Flourney as formations and proposed that the Umpqua Formation of Diller be used. A formation is a lithological mappable unit. The three formations, formerly parts of Diller's Umpqua Formation, are such mappable—and mapped—units and should stand on their own merits. Distinguishing these formations from each other is important to understanding the tectonic development of southwestern Oregon. To do less is to obscure the geology.

## ROTATION OF THE EOCENE UNITS

Simpson and Cox (1977) and other authors have shown that western Oregon has undergone 50°-70° clockwise rotation in an

area from the Klamath Mountains to a point north of Newport in the Coast Range. If the Coast Range rotated as a block, the location of the axis of rotation is unclear. This complex problem has been studied by Wells and Heller (1988). Although no clear answer is known, they ascribe rotation to a combination of movement of the colliding plates and stretching of the Great Basin. As noted in this article, the interpreted rotation must be factored into statements of location and paleogeography at various points in time. The place of the reconstruction implied here in interpretations of Eocene plate tectonics is touched on but is not the subject of this paper.

## ACKNOWLEDGMENTS

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# Cyanide in mining

by Allen H. Throop, Mined Land Reclamation Program, Oregon Department of Geology and Mineral Industries, 1534 Queen Avenue SE, Albany, Oregon 97321

A new application of old technology combined with favorable prices has revolutionized the gold mining industry. The effects of the revolution are now being felt in Oregon. New applications of cyanide technology are allowing profitable mining of lower grades of ore.

For over 100 years, metallurgists have used cyanide to dissolve and recover gold and silver from some ores by leaching. About 15 years ago, the U.S. Bureau of Mines designed a recovery method combining the efficiency of cyanide leaching with modern large-scale, open-pit mining techniques. Nevada, California, Idaho, and Washington are among the states where, in recent years, gold mining has increased dramatically because of these contemporary methods. Oregon should soon join them.

## THE PROCESS

Heap leaching gold from ore is, in a general way, similar to the geologic processes that concentrated native copper in the huge Arizona deposits that initially drew miners to that state. In those copper deposits, acidic waters dissolved copper from low-grade deposits and then, as conditions changed, redeposited and concentrated the copper into economically recoverable orebodies. In a typical heap leaching process, a weak solution of cyanide dissolves low-grade gold and then redeposits the gold on activated carbon from which the now more concentrated gold can be economically recovered.

Because each deposit is unique, the nature of the ore and, consequently, the details of mining and processing vary from site to

site. For example, although only gold is mentioned in this article, the cyanide heap leaching process also recovers silver.

A typical sequence used in heap leaching is as follows:

Ore is drilled and blasted from an open pit. A ton of ore may contain less than 0.05 oz of gold. Recovering this gold might be compared to finding the fragments of a pulverized rice grain in a rock the size of a refrigerator.

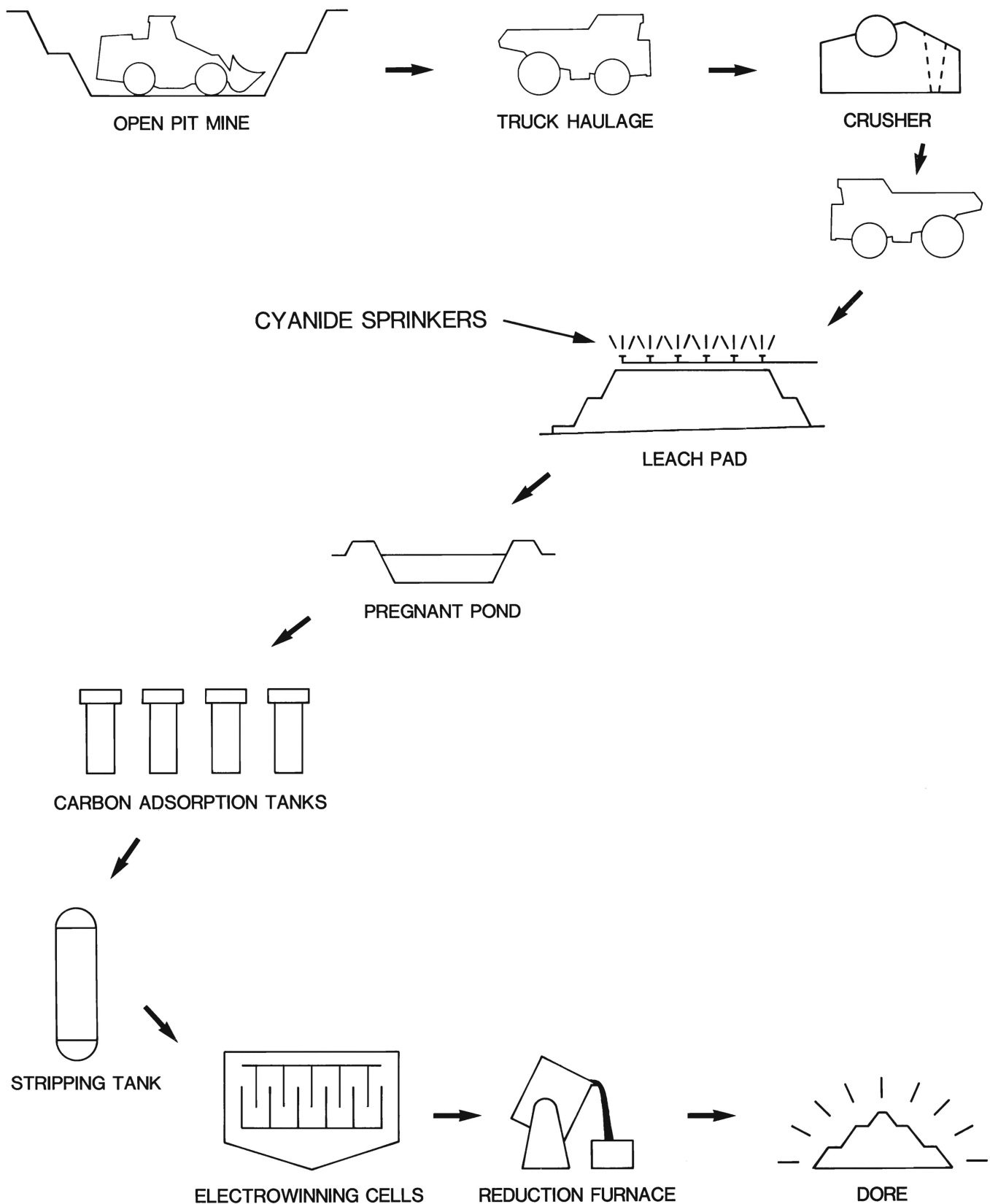
After blasting, large front-end loaders dump the ore into trucks that carry it to the processing site. The ore is next crushed into pieces that are three-quarters of an inch or less in diameter. After crushing, trucks or conveyors heap the crushed rock in piles 50 ft or deeper on large, specially built pads that can cover many acres.

Once the heaps are built on the pad, plastic pipes with sprinklers are laid on top of the ore. A weak cyanide solution is then sprayed over the heaps. It trickles through the ore and dissolves the microscopic gold particles. After reaching the bottom of the heap, the gold-bearing solution collects in pipes. Because it contains gold, miners refer to the liquid as the "pregnant" solution. From the heaps, the pregnant solution flows to the pregnant pond, where it is held to await further processing.

At a constant rate, pumps move the pregnant solution from the pond to a series of columns filled with carbon. The gold in the pregnant solution is quickly adsorbed onto the carbon. Once the metal is stripped from the liquid, the now barren solution is sent to a second holding pond, the barren pond. The solution is treated to have the correct alkalinity and the proper cyanide content restored and is then pumped back to the leach pad to start the cycle over again.



Aerial view of gold mine and processing facilities of Atlas Gold Mining, Inc., in Eureka, Nevada. 1=open-pit mine; 2=waste dumps; 3=crusher and mill; 4=administration, laboratory, and maintenance buildings; 5=heap leaching pad; 6=carbon columns; 7=pregnant pond; 8=barren pond; 9=fresh-water pond. Photo courtesy of Atlas Gold Mining, Inc.



*Simplified heap leach flow chart, showing the main steps from mined ore to refined gold. At the end of the process, the "dore" that is poured into bars is 90 percent pure gold.*



*Base preparation of heap leach pad. On a slightly inclined surface, an impermeable plastic sheet (darker in color) is covered with a highly permeable synthetic material (lighter color). The permeable sheet and the perforated pipes serve to drain off the leaching solution after it has moved from the top to the bottom of the ore pile and become "pregnant." Under the impermeable sheet and not visible in the picture, a leak detection system is installed.*

The carbon is removed from the columns, when it has adsorbed as much gold as possible. A stronger cyanide solution redissolves the precious metal, which is then precipitated onto steel wool. The steel wool/gold mixture is melted in a furnace, and iron and other impurities go into slag that is separated from the gold. The "dore" that is finally poured from the furnace into bars is now 90 percent pure gold. Final refining takes place away from the mine site. After mining, hauling, milling, and leaching the ore, the mining company will receive less than \$20 for the gold in each ton of ore.

## GOLD MINING IN OREGON

During the last 20 years, most of Oregon's gold production has been from placer deposits in Baker, Malheur, Grant, Josephine, and Douglas Counties. Such deposits consist of coarse gold particles mixed in gravels. Since gold is much denser (heavier) than gravel, processing the ore through a trommel and sluice box works well to separate the precious metal from the gravel, and cyanide is not generally used in placer mining. Gravity methods are cheaper, and gold nuggets sold for jewelry bring prices higher than the price for refined gold.



*Cyanide solution being applied on heap leach pad at Atlas Mine. Photo courtesy of Atlas Gold Mining, Inc.*



*Heap leach pad in production. Only the section in background is currently being sprinkled with cyanide solution.*

However, the cyanide leaching technology has encouraged geologists to look at areas where they might find large deposits of low-grade and very fine gold. Only recently have exploration companies focused their attention on Oregon.

Several deposits have been found and are now undergoing advanced exploration and feasibility studies. Galactic Services and Wavecrest are working at Quartz Mountain in Lake County. Atlas Precious Metals is working in Malheur County. Many other exploration projects are active in central and eastern Oregon.

One deposit in Grant County has now been developed to the point where GSR Goldsearch Resources (US), Inc., a subsidiary of a Canadian company and the company that will operate the Grant County mine, has received all the necessary permits for a mining operation. The permitted operation is known as the Prairie Diggings Mine.



*Example of carbon columns used to remove gold from pregnant solution.*

## WHAT IS CYANIDE?

Chemically, the word "cyanide" refers to several compounds of carbon and nitrogen which are often combined with other elements. For the leaching process, the U.S. mining industry starts with solid sodium cyanide (NaCN) and mixes it in a highly alkaline solution (pH of 10.5 or greater) before spraying it on the leach pad. The alkalinity must be kept high to prevent a breakdown of the solution and loss of the cyanide into the atmosphere as a gas.

To humans, fish, and other animals, cyanide is very toxic. Eating a piece of sodium cyanide equal to half a rice grain can be fatal

*(Continued on page 20, Cyanide)*



# Ice-Age glaciers and lakes south of the Columbia River Gorge

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, Portland, Oregon 97207-0751

## ABSTRACT

Geomorphic analysis of the 600 mi<sup>2</sup> lying between the Columbia and Sandy-Zigzag Rivers, based on 26 topographic maps with scales varying from 1:125,000 to 1:24,000, has determined that a minimum of 60 mi<sup>2</sup> or 10 percent of the total area was covered by ice during the Pleistocene by two large glaciers, one in the valleys of the Sandy and Zigzag Rivers and one in the valley of the West Fork Hood River, and 52 small glaciers that chiseled the upper north and east slopes of the volcanic upland above elevations of 3,000 ft. Small tarns and morainal lakes occupy 14 of the cirques.

## INTRODUCTION

Fourteen years ago, I published an article (Allen, 1975), that described, largely from a geomorphic or landform study of 12 topographic maps, the extent and characteristics of the Ice Age glaciers that covered 337 mi<sup>2</sup> of the Wallowa Mountains in north-eastern Oregon. That study involved the recognition of 13 kinds of landforms produced by mountain glaciers, eight of them erosional in origin (matterhorn, arete, col, cirque, tarn lake, bastion, U-shaped valley, and hanging valley) and five depositional in origin (terminal, lateral, and recessional moraine; morainal lake; and glacial outwash plain).

I have been interested in the area lying between the Columbia River Gorge and the Sandy and Zigzag Rivers ever since I traversed most of its ridges in 1931, while contributing to one of its first reconnaissance geologic maps (Allen, 1932). Logging of these upland surfaces had been completed a few years earlier and had bared much of the topography. Now, however, decades of new growth have subdued and mantled the glacial features.

For several years, I have been plotting these features on older 15- and 30-minute quadrangle maps that were made in the field by skilled cartographers using plane table methods, their knowledge of geomorphology—and some artistic license. Since 1975, more than 20 new 7½-minute quadrangles of the area between the Sandy and Zigzag Rivers and the Columbia River Gorge have been released. I had hoped that the new maps, which were made with more sophisticated techniques and are more accurate than the older maps, would also be more helpful in the geomorphic study of the area's glaciation. But I soon realized that the older, more interpretative maps were more useful for this purpose. For that reason, a 1907 base map is used in this paper to illustrate the glaciation.

In this analysis, three of the 13 landforms listed as criteria of glaciation evidence for the Wallows—*arete*, *bastion*, and *matterhorn*—were discarded as inappropriate for the area around the Gorge. I have also added three criteria: The landform is at an elevation above 3,000 ft, it is on an east or northeast slope, and it is one of a group of at least three similar nearby landforms located in similar topographic positions. In order to be included on the map presented in this paper, a glacial landform had to display at least four of the 13 distinguishing features.

It is important to note that the map shows the absolute minimum area covered by ice during the Ice Age. It may well have amounted to twice the 60 mi<sup>2</sup> suggested.

## GEOLOGIC SETTING

North and west of Mount Hood, the pre-Ice Age plateau consisted of numerous, mostly Pliocene (2- to 5- million year [m.y.] old) coalescing and overlapping shield volcanoes lying along and

south of a line between Larch Mountain on the west and Mount Defiance on the east.

Relatively undissected areas surround many of these volcanoes (Larch, Palmer, Talapus, Eagle, Big Bend, Aschoff, Green Point, Hiyu, Lost Lake, and Defiance) and also occur at Latourelle Prairie and Benson Plateau.

The present Columbia River Gorge was cut during the last 3 m.y. (M.H. Beeson, personal communication, 1987), and the upland surface was deeply dissected by the Bull Run, Sandy, and Hood Rivers and their tributaries, as well as by Herman, Eagle, Tanner, and other lesser creeks that drain to the Columbia. This dissection also cut away much of several other volcanic peaks (Nesmith, Tanner, Chinidere, and Indian).

## GLACIERS

During the last 2 m.y. (Pleistocene), the upper sides of many of the higher peaks, ridges, and plateau remnants in the 600-mi<sup>2</sup> area were carved by at least 52 small glaciers that, except for glaciers in the valleys of Sandy River, Zigzag River, and the West Fork Hood River, rarely extended down below 3,000 ft in elevation.

Fifteen thousand years ago, glaciers on Mount Hood were probably much different and certainly were much larger than today. Three of the west-side glaciers (now Zigzag, Reid, and Sandy Glaciers) then joined and extended 20 mi down the Sandy River valley and may have even extended northwest of Marmot toward the Little Sandy River to a point only 6 mi east of the present-day town of Sandy. This Sandy River glacier produced by far the largest number of landforms, and, along with its Zigzag River tributary, covered more than 35 mi<sup>2</sup> of those valleys below the slopes of Mount Hood. The glacier filled its valley with ice to a depth of at least 1,000 ft near its western end, since outwash overflowed north into the Little Sandy River valley through three saddles in the ridge between Marmot and Brightwood. The glacier both widened and deepened the valley, steepened its walls, and left terminal and recessional moraines that now occupy the center of the northward bend of the river at Alder Creek. A south-side lateral moraine forms the lower parts of the hills south of Highway 26 for 4 mi west of Brightwood, and hummocky ground moraine may be seen near Cherryville.

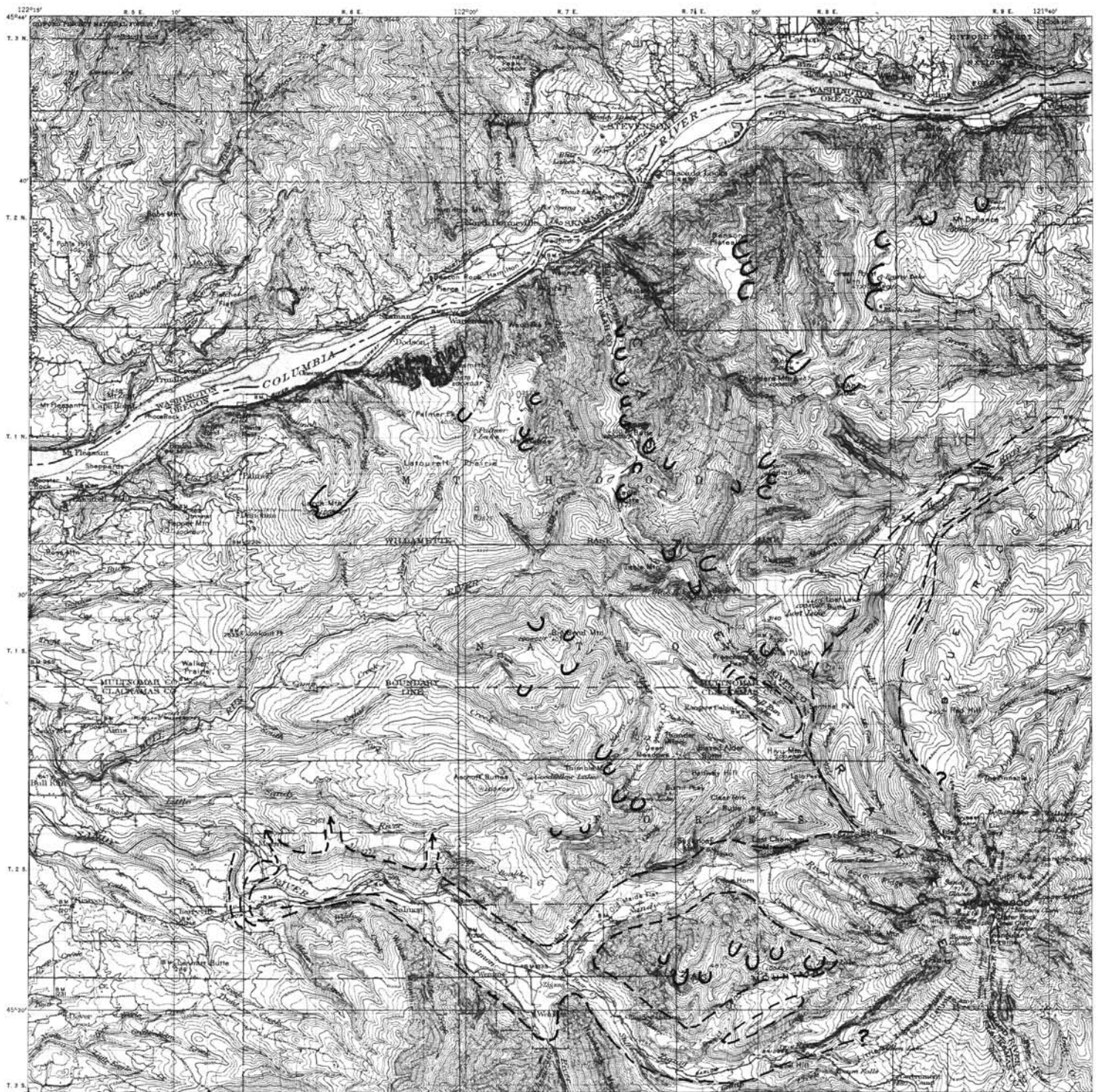
It is probable that most of the features described here were results of the last Vashon or Pinedale glaciation (Crandell, 1965), which culminated 15,000 years ago. Many earlier and possibly just as extensive advances of ice occurred during the 2 m.y. of the Pleistocene, but field work will be required to prove their presence and extent.

Although today only the Glisan and Ladd Glaciers contribute to the West Fork Hood River, its valley once contained a large glacier that covered more than 15 mi<sup>2</sup>. The glacier came down the valley to near the outwash plain that is now Dee Flat, and terminal, recessional, and lateral moraines can be inferred from the topography along the West Fork. If the upper part of this glacier was more than 1,000 ft thick, it would have spilled over the col north of Hiyu Mountain into the headwaters of the Bull Run River to scour out the Bull Run Lake basin.

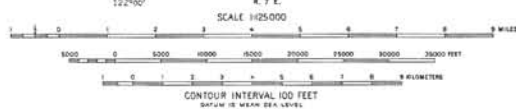
Evidence of the Ice Age extent of the glaciers originating on the other three sides of Mount Hood has been largely covered by volcanic debris from explosive eruptions (pyroclastic flows) and lahars (mudflows) during the last 10,000 years.

The largest of the 52 smaller glaciers was on the northeast side





R. B. Marshall, Chief Geographer  
T. G. Gerdine, Geographer in charge  
Topography by A. H. Sylvester, Ralph Cowgill, R. M. LaFollette,  
T. P. Randerson, E. L. Selton, and E. R. Johnson  
Control: Coast and Geodetic Survey, C. F. Orquhart,  
J. M. Carlick, George Neuner, Jr., and S. H. Stone  
Surveyed in 1907 and 1908-1911



MOUNT HOOD AND VICINITY, OREG.-WASH.  
N 45° 10' - W 121° 39' 20" X 30  
1911



Glacial cirques

Limits of glaciation and moraines

Map showing glaciation of the area between the Columbia River Gorge and the Sandy and Zigzag Rivers. The base map used is a 1907 U.S. Geological Survey map, which is rather interpretative and shows some of the glacial features more clearly than newer maps of the area.

of Larch Mountain and once covered more than a square mile. Most of the rest of the glaciers formerly covered areas of half to a quarter of a square mile or less. The headwalls of their cirques or glacial amphitheatres were usually less than 700 ft high. If the average area is about a third of a square mile, these small glaciers covered a total of 17 mi<sup>2</sup>.

## LAKES

Eighteen, or 35 percent, of these cirques still contain remnants of small tarns or morainal lakes. The east side of "County Line Ridge," between Eagle and Tanner Creeks, has 10 cirques in the 9 mi between Table Mountain and Wauna Point south of Bonneville Dam, and four of them contained lakes in the 1907 map used for this study. Five cirques around Mount Defiance contain lakes. Four of the seven cirques on the north side of Zigzag Mountain contain lakes.

The glacial origin of Wahtum, Lost, and Bull Run Lakes has been questioned. Although called a glacial lake in the *Atlas of Oregon Lakes* (Johnson and others, 1985), Wahtum Lake, with a depth of 184 ft, could be a diatreme or phreatic (steam) volcanic explosion crater. Lost Lake probably lies within a glaciated valley, but the lake was formed by a lava dam from Lost Lake volcano.

According to Beaulieu (1974), Bull Run Lake basin was partially formed by a lava flow. However, the valley is U-shaped, the head of the lake is cirquelike, and there is morainal material on top of the lava at the northwest end of the lake.

These and the 14 other small lakes contain spores and pollen in the sediment on their floors. Probably many more of the 52 cirque basins once contained lakes that now have changed to swamp or meadow.

Hansen (1946, 1947) was the first in Oregon to use the priceless scientific pollen record entombed in Oregon lakes and swamps to

determine the different kinds of plants that occupied the area and the sequences of climatic changes that have occurred during the last 10,000 years. The investigation of the pollen record from Battleground Lake, north of Vancouver, Washington (Barnosky, 1985), which is the latest of these studies that have added much to our knowledge of the postglacial period, is a good model for future pollen studies in the Cascades.

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## Rock eaters at work

The involvement of biological agents in the decomposition of rocks has attracted increased attention in recent years, particularly in the area of preserving historic structures. Scientists have found that, until now, the role of microorganisms in the deterioration of stone and similar building materials has been largely underestimated.

Wilhelm Irsch reports in *Die Zeit* (Overseas edition, no. 38) on findings of scientists in Germany, where the Federal Government supports investigations by such groups as the geomicrobiology research team at the University of Oldenburg. Here, geologists, biologists, chemists, and physicists are collaborating in studies of the effects of the numerous organisms that attack buildings. These tiny "rock eaters" include lichens, algae, fungi, molds, and bacteria. Thus, for instance, fungi closely related to those growing in marmalade jars have been found occurring widely on rocks; even wastewater organisms have been discovered on rocks.

The same rapid processes of decomposition that affect organic substances, for instance, the spoiling of fresh food or the rotting of animal cadavers, are applicable in the biologic deterioration of minerals. The "rock eaters" attack not only stone and concrete but also glass, metals, sheet rock, paints, and wall paper.

These organisms may attack building materials directly or indirectly, for instance, through acids or salts that they produce and that migrate and concentrate in the stone or concrete; they may spread the same substances through the atmosphere, through ground water, or through rain or condensation moisture that migrates within the building materials. Such substances include nitric, sulfuric, and carbonic acids as well as organic acids. It was found that considerable effects on stone were produced not only by nitric oxides from automobile emissions but also by nitric oxides produced by bacteria that "eat" ammonium and ammonia compounds and whose origin is still a mystery. In addition, there are mechanical destructive ef-

fects, such as biological blasting and splitting through growth processes or the formation of gases and indirect effects through influences on many chemical processes that occur in the building material even without the presence of the "little wreckers."

Because of the minute size of microorganisms, it is hard to imagine the size of the problem these colonizers represent. For example, the Cologne Cathedral contains approximately five million stones. Microorganisms populate these stones to a depth of 5 cm from the surface, at an average density of at least 100,000 bacteria per cm<sup>3</sup>. That means that the fantastic number of approximately ten quadrillion (10<sup>16</sup>) microorganisms live on—and eat from—the Cathedral. The speed of their reproduction and their metabolic activity are beyond description.

To the microscope view of the scientist, the microflora of building-material surfaces assumes the dimensions of a tropical rain forest, and large cities appear as so many "lands of milk and honey" for microbes.

Modern cities, it seems, are particularly fertile areas for rock-eating microbes. During a study of the process of colonization, it was found that the microflora of rocks brought into the city as building materials increased a hundredfold within six months, from 20,000 per gram of rock material to two million.

For sources of energy, microbes use the sun as well as chemical energy from inorganic compounds or from organic ones such as coal, oil, methane, wood, protein, or paper. The microbes' "menu" ranges from carbon, nitrogen, sulfur, oxygen, and hydrogen to phosphorus and various salts. Gradually, through the feasting of the microbes, building materials not only lose substance but also change their chemical composition.

So far, protective substances used to preserve building materials were not aimed at controlling such processes. Thus, there exists a considerable need to catch up in the study of microbial "rock eaters."

—Klaus Neuendorf



# Collecting rocks

Modified from a U.S. Geological Survey pamphlet, "Collecting Rocks," by Rachel M. Barker

## THE EARTH'S STORY IN ROCKS

Rocks are the very substance of the Earth. They are composed of the same elementary particles as all other matter in the universe, but the particles are so arranged in rocks that the aggregate masses are very extensive. Individual rock bodies commonly occupy hundreds or thousands of cubic miles of the Earth's volume. Even so, they differ greatly from place to place because of the many different rock-forming processes.

What rocks are like at depths within the Earth is known only imperfectly from indirect measurements made by various techniques. Rocks near the surface, however, have been studied for many years, and their characteristics are well known. Studies of rocks have taught much about the structure, composition, and history of the Earth. In fact, the success of geologists in reconstructing the Earth's story by piecing together information from rocks is one of the wonders of science.

Geologists classify rocks in three great groups according to the major Earth processes that formed them. The three groups are **igneous rocks**, **sedimentary rocks**, and **metamorphic rocks**. Anyone who wishes to build a meaningful rock collection should become familiar with the characteristics and interrelationships of these great groups. To transform a random group of rock specimens into a true collection, application of the geologic principles on which rock classification is based is necessary.

Igneous rocks are formed from molten material that has cooled and solidified. Molten rock material originates deep within the Earth and ascends to lesser depths or even, in volcanic eruptions, to the Earth's surface. When it cools slowly, usually at depths of thousands of feet, crystals separate from the molten liquid, and a coarse-grained rock results. When it cools rapidly, usually at or near the Earth's surface, the crystals are extremely small, and a fine-grained rock results. Separate bodies of molten rock material have, or acquire, unlike chemical compositions and solidify to different kinds of igneous rocks. Thus, a wide variety of rocks is formed by different cooling rates and chemical compositions. Dissimilar as they are, obsidian, granite, basalt, and andesite porphyry are all igneous rocks.



*Coarse-grained igneous rock (granite).*

Sedimentary rocks are formed at the surface of the Earth, either in water or on land. They are layered accumulations of sediments—fine to coarse fragments of rocks, minerals, precipitated chemical matter, or animal or plant materials. At no time during their formation are temperatures or pressures especially high, and their mineral constitutions and physical appearances reflect this fact. Ordinarily,

sedimentary rocks become cemented together by minerals and chemicals or are held together by electrical attraction; some, however, remain loose and unconsolidated. The layers are normally parallel or nearly parallel to the Earth's surface; if they are at high angles to the surface or are twisted or broken, some kind of Earth movement has occurred since deposition.

Most people visualize more easily the formation of sedimentary rocks than that of igneous or metamorphic rocks, because the process occurs around us all the time. Sand and gravel layers on beaches or in river bars resemble sandstone and conglomerate. Mud flats need only to be compacted and dried to become shale. Scuba divers who have seen mud and shells settling on the floors of lagoons find it easy to understand the formation of sedimentary rock.



*Sedimentary rock (conglomerate).*

Sometimes, sedimentary and igneous rocks are subjected to pressures so intense or to heat so high that they are completely changed. They become metamorphic rocks, which form while deeply buried within the Earth's crust—usually during the long continued series of gigantic events that produce mountain systems. The process of metamorphism does not melt the rocks, but instead transforms them into denser, more compact, **foliated** rocks. (Foliated means the parallel arrangement of certain mineral grains that gives the rock a laminated appearance.) New minerals are created either by rearrangement of mineral components or by reactions with fluids that enter the rocks. Some kinds of metamorphic rocks—granite gneiss and biotite schist are two examples—are strongly banded or foliated. Other kinds, such as hornfels and quartzite, are massive. Stress or temperature can even change previously metamorphosed rocks into new types.

A peculiarity of metamorphic rocks is that, with increasing metamorphism, a related but unlike series of rocks is formed. Thus, in favorable localities, one can trace a formation from shale through slate to phyllite, to biotite-muscovite schist, and then to biotite gneiss—and know that all the rock types evolved from the same shale. Elsewhere, it may be impossible to tell which of two such dissimilar rocks as basalt and limy shale was the parent rock of hornblende schist.

Rock-forming and rock-destroying processes have been active for several billion years. Today, in the Guadalupe Mountains of western Texas, one can stand on limestone, a sedimentary rock, that was a coral reef in a tropical sea about 250 million years ago. In Vermont's Green Mountains one can see schist, a metamorphic rock, that was once mud in a shallow sea. Half Dome in Yosemite Valley, California, which now rises nearly 8,800 ft above sea level, is com-



*Metamorphic rock (schist) with alternate bands of light and dark minerals (foliation).*

posed of quartz monzonite, an igneous rock that was emplaced and solidified several thousand feet within the Earth. To realize that a simple collection of rocks can illustrate this tremendous sweep of Earth history is an inspiring thought.

### STARTING A COLLECTION

A good rock collection consists of selected, representative specimens, properly labeled and attractively housed. It can be as large or as small as its owner wishes. An active collection constantly improves, as specimens are added or as poor specimens are replaced by better ones.

A rock collection might begin with stones picked up from the ground near one's home. These stones may have little value in the collection and can be replaced later by better specimens. Nevertheless, this first step is helpful in training the eye to see diagnostic features of rocks (features by which rocks can be differentiated). As one becomes more familiar with collecting methods and with geology, the collection will probably take one of two directions. One may try either to obtain representative specimens of igneous, sedimentary, and metamorphic rocks, or to collect all the related kinds of rocks from particular geologic provinces.

### IDENTIFYING ROCKS

Many books about geology explain the identification and classification of rocks and describe the underlying geologic principles. Almost any recent general book on geology would help a rock collector.

Geologic maps, unsurpassed as collecting guides, are also excellent identification aids. They show the distribution and extent of particular rock types or groups of rock types. Depending on size and scale, the maps may cover large or small areas. Most have brief descriptions of the rock types. Some are issued as separate publications; others are included in book reports.

Most geologic maps are issued by public or private scientific agencies. The U.S. Geological Survey (USGS) booklet, *Geologic and Water-Supply Reports and Maps for Oregon*, provides a ready reference to USGS publications about Oregon. The free booklet may be obtained by writing to Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225.

The Oregon Department of Geology and Mineral Industries (DOGAMI) has published numerous maps and books on the geology of Oregon (see list of available publications on pages 23 and 24 of this issue). DOGAMI has just released an updated version of an old favorite publication for rock and mineral collecting in Oregon, entitled *A Description of Some Oregon Rocks and Minerals* (see article on page 18 of this issue). This report describes the types of rocks and minerals found in Oregon and would be useful for rock collecting in this state. DOGAMI publications are sold in the Depart-

ment's Portland, Baker, and Grants Pass offices (see addresses on page 2 of this issue) and are also available in many local libraries.

Comparing one's own specimens with those in a museum collection can help in identifying them. Most large rock collections are well labeled. Smaller rock collections abound in libraries, schools, public buildings, small museums, and private homes.

### WHERE TO FIND ROCKS

Collections usually differ markedly depending on where the collector is able to search for rocks. In the great interior plains and lowlands of the United States, sedimentary rocks are exposed in wide variety. Igneous and metamorphic rocks are widespread in the mountains and piedmont areas of New England, the Appalachians, the Western Cordillera, and scattered interior hill lands; igneous rocks make up almost all the land of Hawaii. Along the Atlantic and Gulf Coastal Plains and locally elsewhere, loose and unconsolidated rocks are widespread; in northern areas, glaciers deposited many other unconsolidated rocks.

The best collecting sites are quarries, road cuts or natural cliffs, and outcrops. Open fields and level country are poor places to find rock exposures. Hills and steep slopes are better sites. Almost any exposure of rock provides some collecting opportunities, but fresh, unweathered outcrops or manmade excavations offer the best locations. Where feasible, it is a good plan to visit several exposures of the same rock to be sure a representative sample is selected.

### COLLECTING EQUIPMENT

The beginning collector needs two pieces of somewhat specialized equipment—a geologist's hammer and a hand lens.

The hammer is used to dislodge fresh rock specimens and to trim them to display size. It can be purchased through hardware stores or scientific supply houses. The head of a geologist's hammer has one blunt hammering end. The other end of the most versatile and widely used style is a pick. This kind of hammer is aptly called a geologist's pick. Another popular style—the chisel type—has one chisel end; it is used mostly in bedded, soft sedimentary rocks and in collecting fossils.

The hand lens, sometimes called a pocket magnifier, is used to identify mineral grains. Hand lenses can be purchased in jewelry stores, optical shops, or scientific supply houses. Six-power to ten-power magnification is best. Optically uncorrected hand lenses are inexpensive and quite satisfactory, but the advanced collector will want an optically corrected lens.



*Rock hammer and hand lens.*

Other pieces of necessary equipment are neither unusual nor expensive: a knapsack to carry specimens, equipment, and food; paper sacks and wrapping paper in which to wrap individual specimens and a marking pen to mark them; a notebook for keeping field notes until more permanent records can be made; and a pocket knife, helpful in many ways, especially to test the hardness of mineral grains.

*(Continued on page 22, Rocks)*

# The severity of an earthquake

Interest in earthquakes in Oregon has been spurred recently by the hypothesis that the Juan de Fuca Plate may subduct beneath Oregon and Washington in a series of very large but infrequent earthquakes.

The National Earthquake Hazard Reduction Program has funded the Oregon Department of Geology and Mineral Industries (DOGAMI) for a five-year study aimed at predicting the local intensity of earthquakes in the Portland area, based on geology. Because it is important to understand the distinction between the magnitude of an earthquake and its intensity, we are reprinting the following discussion of earthquake intensity and magnitude from a U.S. Geological Survey pamphlet, *The Severity of an Earthquake*. Copies of this pamphlet may be obtained free from the Book and Open-File Reports Section, U.S. Geological Survey, Federal Center, Box 25425, Denver, CO 80225. Single free copies are also available at the Portland Office of DOGAMI (address on page 2 of this issue).

The severity of an earthquake can be expressed in terms of both **intensity** and **magnitude**. However, the two terms are quite different, and they are often confused by the public.

Intensity is based on the observed effects of ground shaking on people, buildings, and natural features. It varies from place to place within the disturbed region depending on the location of the observer with respect to the earthquake epicenter.

Magnitude is related to the amount of seismic energy released at the hypocenter of the earthquake. It is based on the amplitude of the earthquake waves recorded on instruments that have a common calibration. The magnitude of an earthquake is thus represented by a single, instrumentally determined value.

Earthquakes are the result of forces (deep within the Earth's interior) that continuously affect the surface of the Earth. The energy from these forces is stored in a variety of ways within the rocks. When this energy is released suddenly, for example by shearing movements along faults in the crust of the Earth, an earthquake results. The area of the fault where the sudden rupture takes place is called the **focus** or **hypocenter** of the earthquake. The point on the Earth's surface directly above the focus is called the **epicenter** of the earthquake.

## THE RICHTER MAGNITUDE SCALE

Seismic waves are the vibrations from earthquakes that travel through the Earth; they are recorded on instruments called seismographs. Seismographs record a zigzag trace that shows the varying amplitude of ground oscillations beneath the instrument. Sensitive seismographs, which greatly magnify these ground motions, can detect strong earthquakes from sources anywhere in the world. The time, location, and magnitude of an earthquake can be determined from the data recorded by seismograph stations.

The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included in the magnitude formula to compensate for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude of 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

At first, the Richter Scale could be applied only to the records from instruments of identical manufacture. Now, instruments are carefully calibrated with respect to each other. Thus, magnitude can be computed from the record of any calibrated seismograph.

Earthquakes with magnitude of about 2.0 or less are usually called microearthquakes; they are not commonly felt by people and are

generally recorded only on local seismographs. Events with magnitudes of about 4.5 or greater—there are several thousand such shocks annually—are strong enough to be recorded by sensitive seismographs all over the world. Great earthquakes, such as the 1906 Good Friday earthquake in Alaska, have magnitudes of 8.0 or higher. On the average, one earthquake of such size occurs somewhere in the world each year. Although the Richter Scale has no upper limit, the largest known shocks have had magnitudes in the 8.8 to 8.9 range. Recently another scale called the moment magnitude scale has been devised for more precise study of great earthquakes.

The Richter Scale is not used to express damage. An earthquake in a densely populated area that results in many deaths and considerable damage may have the same magnitude as a shock in a remote area that does nothing more than frighten the wildlife. Large-magnitude earthquakes that occur beneath the oceans may not even be felt by humans.

## THE MODIFIED MERCALLI INTENSITY SCALE

The effect of an earthquake on the Earth's surface is called the intensity. The intensity scale consists of a series of certain key responses such as people awakening, movement of furniture, damage to chimneys, and, finally, total destruction. Although numerous intensity scales have been developed over the last several hundred years to evaluate the effects of earthquakes, the one currently used in the United States is the Modified Mercalli (MM) Intensity Scale. It was developed in 1931 by the American seismologists Harry Wood and Frank Neumann. This scale, composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, is designated by Roman numerals. It does not have a mathematical basis; instead, it is an arbitrary ranking based on observed effects.

The Modified Mercalli Intensity value assigned to a specific site after an earthquake provides a measure of severity that is more meaningful to the nonscientist than the magnitude, because intensity refers to the effects actually experienced at that place. After the occurrence of a widely felt earthquake, the Geological Survey mails questionnaires to postmasters for distribution in the disturbed area, requesting information so that intensity values can be assigned. The results of this postal canvass and information furnished by other sources are used to assign an intensity value and to compile isoseismal maps that show the extent of various levels of intensity within the area where the earthquake was felt. The maximum observed intensity generally occurs near the epicenter.

The lower numbers of the intensity scale generally deal with the manner in which the earthquake is felt by people. The higher numbers of the scale are based on observed structural damage. Structural engineers usually contribute information for assigning intensity values of VIII or above.

The following is an abbreviated description of the 12 levels of Modified Mercalli intensity:

I. Not felt except by a very few, under especially favorable conditions.

II. Felt only by a few persons at rest, especially on upper floors



of buildings. Delicately suspended objects may swing.

**III.** Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.

**IV.** Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

**V.** Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

**VI.** Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

**VII.** Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.

**VIII.** Damage slight in specially designed structures; considerable damage in ordinary substantial buildings, with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

**IX.** Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

**X.** Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

**XI.** Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

**XII.** Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Another measure of the relative strength of an earthquake is the size of the area over which the shaking is noticed. This measure has been particularly useful in estimating the relative severity of historic shocks that were not recorded by seismographs or did not occur in populated areas. The extent of the associated areas where effects were felt indicates that some comparatively large earthquakes have occurred in the past in places not considered by the general public to be regions of major earthquake activity. For example, the three shocks in 1811 and 1812 near New Madrid, Missouri, were each felt over the entire eastern United States. Because there were so few people in the area west of New Madrid, it is not known how far the shocks were felt in that direction. The 1886 earthquake at Charleston, South Carolina, was also felt over a region of about 2 million square miles, which includes most of the eastern United States. □

### New geologic postcard available

A colorful postcard has been created in the Oregon Department of Geology and Mineral Industries and is now available for sale.

The card pictures color representations of the State Rock, the thunderegg, and a faceted specimen of the State Gemstone, the Oregon sunstone, along with some explanatory text. White print and color-photo inserts are set on a black background.

Price of the postcard is 50 cents. For ordering, see the Department's Portland address on page 2 of this issue. Orders under \$50 require prepayment.

## DOGAMI releases new publications

### BREITENBUSH AREA REPORT

A new geologic report on studies of an area that includes the Austin and Breitenbush Hot Springs, both so-called Known Geothermal Resource Areas (KGRA) in the Cascade Range, presents a geologic cross section and geothermal model in greater detail than had been possible so far.

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released *Geology and Geothermal Resources of the Breitenbush-Austin Hot Springs Area, Clackamas and Marion Counties, Oregon*, as DOGAMI Open-File Report O-88-5 (price \$8.00). The report was edited by D.R. Sherrod of the U.S. Geological Survey (USGS) and contains contributions by Sherrod and five other scientists from the USGS, Washington State University, and Southern Methodist University.

The report summarizes several ongoing investigations, including geologic mapping, alteration studies, and the heat-flow results from cooperative and industrial drilling programs. The researchers were able to use, for the first time, previously confidential information from industry drilling.

The first five of six chapters present detailed treatments of geologic setting, stratigraphy, geochemistry, and alteration phenomena and analyze a substantial set of new data on thermal conductivity and heat flow. In the final chapter, all the contributions are combined into a geologic cross section showing topography, stratigraphy, structure, isotherms, heat flow, gravity, and hydrology.

The 91-page report is accompanied by a geologic map and cross section of the area around the geothermal drill hole CTGH-1, located about 14 km (8.7 mi) northeast of Breitenbush Hot Springs and 6 km (3.7 mi) northwest of Olallie Butte. This hole was rotary-drilled cooperatively by Thermal Power Company, Chevron Geothermal, and the U.S. Department of Energy in 1986 and yielded an essentially 100-percent core recovery down to its total depth of 161 m (528 ft).

### REVISED GUIDE TO OREGON ROCKS AND MINERALS

Oregon's rocks and minerals are the subject of a newly revised version of an older publication by DOGAMI. *A Description of Some Oregon Rocks and Minerals*, released by the Department as Open-File Report O-88-6 (price \$5.00) was first written by H.M. Dole and published in 1950, and a revised edition appeared in 1976. The new release is the second revision and was prepared by L.L. Brown of the U.S. Bureau of Mines in Albany, originally as a 4-H Leader Guide for the Oregon State University Extension Service.

The 59-page report begins with introductions into the definition, classification, and identification of minerals and rocks in general and then describes individual minerals and rocks. Minerals are grouped into metallic, nonmetallic, and rock-forming minerals; the basic division of rocks into three groups is further divided into such subgroups as extrusive-intrusive igneous rocks, consolidated-unconsolidated sedimentary rocks, and foliated-nonfoliated metamorphic rocks. Individual descriptions include references to the origin and pronunciation of names and to occurrences and economic uses in Oregon.

A bibliography for further reading and a glossary of technical terms used in the descriptions complete the report as a first introduction to the Oregon world of rocks and minerals and their economic significance.

### NEW GEOLOGIC MAP FOR CASCADE HOT SPRINGS AREA

A new geologic map partially funded by the U.S. Department of Energy provides a detailed geologic description of the McKenzie Bridge 15-minute quadrangle in the Cascade Range.

*Geologic Map of the McKenzie Bridge Quadrangle, Lane County, Oregon* was prepared by G.R. Priest, G.L. Black, and N.M. Woller

of DOGAMI and E.M. Taylor of Oregon State University. It was published in DOGAMI's Geological Map Series as Map GMS-48 (price \$8.00).

The McKenzie Bridge quadrangle is located at the transition zone between the older Western Cascades and the younger High Cascades. This zone is also the location of some of the hottest known thermal springs in the Cascade Range. A major purpose of the study that culminated in the production of this map was to define the structure of the area in greater detail.

The report consists of two map sheets and a five-page text discussing the map data. The full-color geologic map at a scale of 1:62,500 (Plate 1) identifies 56 surficial, volcanic, and intrusive rock units and their structural relations and is accompanied by four cross sections. The second sheet (Plate 2) contains index and sample-location maps and three tables showing chemical analyses and radiometric ages of rock samples. The text discusses the structural geology, paleogeographic history, and mineral and geothermal resources of this complex geologic boundary.

### FIRST DETAILED GEOLOGIC MAP FOR OWYHEE REGION

DOGAMI has released the first geologic map that describes in detail the geology and mineral potential of a part of the Owyhee region in Malheur County.

*Geology and Mineral Resources Map of the Owyhee Ridge Quadrangle, Malheur County, Oregon* was prepared by DOGAMI geologist M.L. Ferns with partial funding by the COGEOMAP program of the U.S. Geological Survey and has been published in DOGAMI's Geological Map Series as map GMS-53 (price \$4.00). It is the first published result of an ongoing study of southeastern Oregon areas with a potential for mineral resources.

The Owyhee Ridge 7½-minute quadrangle covers approximately 48 mi² between Lake Owyhee State Park and Succor Creek in Malheur County. At a scale of 1:24,000, the new two-color map describes 20 mostly Tertiary rock units. Structure is described both on the map and in two cross sections. The approximately 28- by 40-in. map sheet also includes a discussion of mineral resources and tables showing whole-rock and trace-element analyses of rock samples.

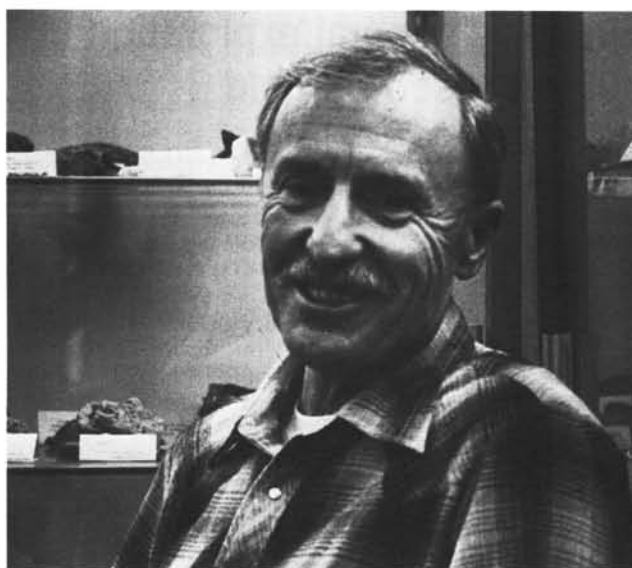
All reports are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. Orders under \$50 require prepayment. □

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## Ramp retires

Len Ramp, 37-year veteran geologist with the Grants Pass Field Office of the Oregon Department of Geology and Mineral Industries, retired on January 1, 1989. Author or coauthor of numerous reports, bulletins, maps, and articles on the geology and mineral resources of the state, Ramp is probably most familiar to *Oregon Geology* readers for his work on Bulletin 61, *Gold and Silver in Oregon*; bulletins on chromite, on the Chetco drainage including the Kalmiopsis Wilderness and Big Craggies Botanical Areas, and on Douglas, Coos, Curry, and Josephine Counties; his investigations of nickel and talc; and geologic maps.

An avid runner, skier, climber, pilot, and river rafter, Ramp's physical skills and endurance are legendary in southwestern Oregon. He was born and raised on a ranch near Roseburg, was graduated from the University of Oregon, and has lived and worked in Grants Pass for many years. Consequently, he has studied and hiked or climbed over most of southwestern Oregon, and his extensive geologic knowledge of the area has been a valuable asset to miners and geologists looking for information. During his tenure with the



Len Ramp. Photo courtesy of Melissa Martin, Medford Mail Tribune

Department, the theory of plate tectonics was developed, and Ramp had the opportunity of being one of the first geologists who were able to apply it to the complex geology of southwestern Oregon. During his retirement, he plans to pursue his numerous hobbies, enjoy the out-of-doors, catch up on projects around his home, and keep in touch with geology.

Ruthie Pavlat, secretary of the Grants Pass Field Office for 18 years, also retired on January 1, 1989. Born in Carbondale, Pennsylvania, Ruthie started life as a coal-miner's daughter but was raised in Binghamton, New York. Married for 45 years to a Navy pilot, Ruthie lived and worked "all over the country." She and her husband tried life in Maui after his retirement but eventually decided to settle permanently near Grants Pass, where they have lived since 1967. Ruthie's hobbies include playing the violin and organ, hiking, fishing and "loving animals," all of which she will continue to enjoy in retirement.



Ruthie Pavlat

Until further notice, the Grants Pass Field office will be open on a part-time basis, on Monday, Tuesday, and Wednesday mornings from 8:00 a.m. until noon. □

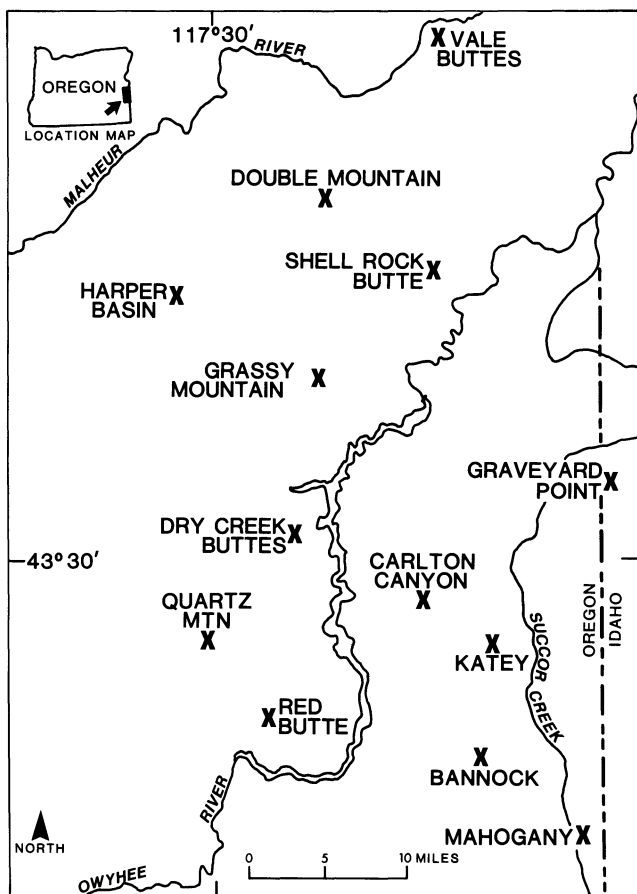
# Oregon's mineral exploration in 1988 focused on gold

Precious metals were the main targets of exploration in Oregon during 1988, with focus on the frontier epithermal (hot-springs) districts of central and southeastern Oregon, as Mark L. Ferns, Oregon Department of Geology and Mineral Industries (DOGAMI) geologist, reported last month in a talk given at the Northwest Mining Association annual convention in Spokane, Washington.

Ferns summarized current exploration and mining activities in Oregon during 1988, commenting particularly on the new developments in the southeastern part of the State and presenting new interpretations of its geology and related precious-metal mineralization.

The announcement by Atlas Corporation of a significant gold discovery at Grassy Mountain, Malheur County, highlighted a summer of extensive exploration. Intense exploration drilling and sampling programs targeted the Vale-Weiser epithermal district in extreme eastern Oregon.

Ongoing mapping projects conducted by geologists from DOGAMI, Portland State University, Washington State University, and the U.S. Geological Survey are resulting in a better understanding of the geologic processes that have generated hot-spring-type gold systems in this area where the northern part of the Basin and Range Province in Oregon intersects with the western part of the Snake River Plain.



Location map of prospects for epithermal gold in southeastern Oregon.

To date, two broad ages of mineralization have been recognized: (1) Early mid-Miocene systems related to caldera formation and Basin and Range extensional environments, exemplified by the Grassy Mountain, Red Butte, Mahogany, Quartz Mountain, and Katey prospects; and (2) younger, late Miocene to early Pliocene systems related to the development of the western Snake River Plain, exemplified by the Vale Buttes, Birch Creek, Shell Rock Butte, and Double Mountain prospects.

The combination of extensional tectonic regimes, areally high heat flow, and favorable host rocks such as arkosic sediments and rhyolite flows and domes make the Vale-Weiser district an especially promising exploration target for epithermal gold systems. □

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## *(Cyanide, continued from page 11)*

to humans; much lower amounts can be fatal to trout. The Oregon Department of Geology and Mineral Industries (DOGAMI) and the Department of Environmental Quality (DEQ) administer regulations that are intended to ensure that cyanide stays within the processing area and does not escape into the ground water or surface water. Working in favor of the environment is the short-lived nature of cyanide. Sunlight, oxygen, or a pH below 8 all lead to the breakdown of cyanide. In addition, cyanide will combine with any iron, other metals, or organic matter that it encounters if it is spilled. Finally, if minute quantities of cyanide do get into animals or humans, the cyanide breaks down quickly. It does not accumulate in the body the way lead, for example, does.

The mention of cyanide tends to get a quick, emotional response from people who are not too well informed about it. Miners familiar with its use know that cyanide is a highly toxic chemical that is generally short-lived in the natural environment and that does a very efficient job of dissolving gold and silver. For an analogy, think of the gasoline in your gas tank. It is toxic and flammable. However, when used properly, it allows you to move around the state quickly and efficiently with very little thought about what would happen if you drank the gasoline.

To carry the analogy further, we don't think about drinking gasoline or cyanide but we do think about both escaping into ground water or into streams. The U.S. Environmental Protection Agency (EPA) and Oregon's DEQ are addressing the serious problem of leaking underground gasoline storage tanks and have developed response programs for surface gasoline spills. New gasoline storage facilities will be designed and built so that leaks and spills are avoided. Likewise DOGAMI and DEQ are working jointly to anticipate and prevent problems of cyanide leaks or spills.

Through existing reclamation laws supplemented by 1987 legislation, DOGAMI has the responsibility of ensuring that mines and leach pads are properly detoxified and reclaimed. The 1987 legislation requires miners to post a bond of between \$25,000 and \$500,000 for removal, detoxification, or cleanup of cyanide at each major facility. DEQ's authority applies to all industrial processes that can affect the environment. The two agencies are working closely to protect the environment, to give miners clear guidance about what is and what is not permissible, and to ensure that adequately prepared permit applications will be reviewed and the permits granted within a reasonable period of time.

Within the next two years, large-scale gold mining using cyanide leaching technology will probably begin in Oregon. To geologists, the low-grade deposits offer new targets for exploration. To state residents, the mines offer increased employment in parts of the state that have chronic high-unemployment problems. Combined with that is the possibility of large developments in areas that now are almost inaccessible. To the regulatory agencies, the use of cyanide offers a challenge to develop adequate controls that protect the environment while not being overly restrictive to the mining companies. □

## Forum on the Geology of Industrial Minerals to meet in Portland

The Oregon Department of Geology and Mineral Industries (DOGAMI) will host the 25th Forum on the Geology of Industrial Minerals in Portland during the week of May 1-6, 1989. The Forum is a conference devoted to the geology, exploration, and production of industrial minerals and typically is attended by 100 to 200 delegates from private industry, government, and academic institutions.

The theme of the 25th Forum will be the industrial minerals of the Pacific Northwest. Papers presented during two days of technical sessions will include summaries of the industrial mineral production and potential of Oregon, Washington, Idaho, and British Columbia as well as discussions of bentonite, calcium carbonate, diatomite, emery, garnet, olivine, perlite, phosphate, pumice, talc, zeolites, and methods of industrial mineral analysis. A half-day field trip will visit local producers and processors, and a 3½-day trip will visit occurrences and producers in eastern and central Oregon.

Further details and registration information are available from Ron Geitgey at the DOGAMI Portland office (see page 2 for address and phone). □

## Symposium on Southern Midcontinent announced

The Oklahoma Geological Survey (OGS) is sponsoring a symposium/workshop dealing with all aspects of Late Cambrian-Ordovician geology of the Southern Midcontinent, to be held in Norman, Oklahoma, October 18-19, 1989.

The symposium/workshop will consist of about 18 papers presented orally and about 20 informal poster presentations. The proceedings will be published by the OGS about eight months after the meeting.

Topics to be covered include sedimentology, diagenesis, petroleum occurrence and exploration, other mineral resources, geologic history, and other subjects important to understanding the geology of Late Cambrian and Ordovician rocks of the region. The area of interest includes all of Oklahoma, northern Texas, the Texas Panhandle, northeastern New Mexico, southeastern Colorado, southern Kansas, southwestern Missouri, and western Arkansas.

All persons who have been doing exploration in the Southern Midcontinent or studies on any of the above-mentioned topics and have an interesting paper to present are invited to submit a preliminary title by March 1, 1989, and an abstract by June 1, 1989. For publication, manuscripts are expected to be completed and submitted by October 1989, at the time of the symposium/workshop.

For further information and submittal of papers, contact Kenneth S. Johnson, Oklahoma Geological Survey, University of Oklahoma, Norman, OK 73019 (phone 405/325-3031).

—Oklahoma Geological Survey news release

## Oregon Ocean Resources Management Task Force meets

The 1987 Oregon Ocean Resources Management Act established a state-level program to plan for coordinated, comprehensive management of ocean uses and resources off the coast of Oregon. The Act strives to balance existing resources and traditional uses of the ocean with new uses by requiring a plan to be written by 1990.

Demands on the ocean for food, energy, minerals, waste disposal,

navigation, and recreation increases the potential for conflict between new and traditional uses of the ocean. At present, there are many State and Federal programs for ocean resources management, but there is no comprehensive management structure. The plan developed under the Act will emphasize management over State waters (the first 3 mi from shore) but will consider sound management in Federal waters (from 3 mi to 200 mi offshore) as well.

The law requires an ocean plan and establishes an overall program for ocean management. A Task Force was established consisting of State and local government representatives, interest-group representatives, and members of the public at large. An Interim Report was prepared in 1988, and the Final Plan is due in July 1990. The Interim Plan is available from the Department of Land Conservation and Development in Portland.

Public involvement has included eight public workshops in the fall of 1988 as well as several Task Force meetings during the year. The next Task Force meeting will be held January 26 and 27 in Charleston, Oregon. Additional public input will be gathered on the Draft Plan at five workshops in October 1989.

The Ocean Resources Management Program publishes a newsletter called *Oregon Ocean*. For a copy of the newsletter or other additional information, contact Eldon Hout, Oregon Department of Land Conservation and Development, Portland, phone (503) 227-6068. □

## Earthquake hazards workshop announced

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces a workshop on earthquake hazards in the area between Portland and the Puget Sound. The workshop will take place March 26-29, 1989, at the Portland Marriott Hotel. It is the second workshop in a five-year series that is part of the Puget Sound/Portland project of the National Earthquake Hazard Reduction Program (NEHRP). The goal of the workshop is to facilitate the spread of technical hazard information and to develop hazard reduction policy.

The Pacific Northwest has become the number-one research target for the NEHRP due to concern over the potential for great earthquakes on the Cascadia subduction zone. The workshop will also focus attention on the hazards of smaller, more "conventional" earthquakes. The program will include

- a technical session on aspects of earthquake sources and effects in the Pacific Northwest;
- a tutorial session on basic earthquake hazard science for attendees without a technical background;
- a session aimed at presenting a scientific consensus of the current hazard status;
- a session devoted to examples of how the technical hazard information can be turned into hazard reduction policy; and
- a field trip to the Oregon coast to examine evidence for great subduction earthquakes.

The program will be cosponsored by the U.S. Geological Survey, the Federal Emergency Management Agency, the Oregon Emergency Management Division, DOGAMI, and the Washington Department of Natural Resources. Representatives from all of these agencies along with geoscientists, engineers, emergency and land use planners, educators, policy makers, and representatives of the insurance and finance industries from Oregon, Washington, California, and British Columbia will be invited to attend. Although attendance at the workshop is by invitation, interested individuals may contact Ian Madin at the Portland office of DOGAMI to be included on the invitation list. □



## NWMA elects new president

The Northwest Mining Association (NWMA) has chosen a Denver mineral expert to lead its members in 1989. Ta M. Li, vice president and general manager for Behre Dolbear-Riverside, Inc., was elected president of the NWMA on November 29, 1988, by the organization's board of trustees. He succeeds Bill Booth of Hecla Mining Company, Coeur d'Alene, Idaho.

Other officers elected or reelected were Mark Anderson, general manager of ASAMERA, Wenatchee, Washington, first vice president; David A. Holmes, exploration manager for Meridian Minerals Co., Englewood, Colorado, second vice president; Karl W. Mote, executive director of the NWMA of Spokane, Washington, vice president; John L. Neff, a Spokane attorney, secretary; and David M. Menard, vice president of Washington Trust Bank in Spokane, treasurer.



*Ta M. Li, NWMA President*

The NWMA was organized in 1895 in Spokane, to support the mineral industry in the Northwest. With headquarters still in Spokane, the Association now has 2,200 members throughout North America, representing all aspects of the mineral industry.

—NWMA news release

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

Publication title: OREGON GEOLOGY, no. 600040; filing date 9-30-88. Published bimonthly, 6 issues per year (monthly until April 1988), annual subscription price \$6. Address of publication office, publisher's business office, editor, and owner: 910 State Office Building, 1400 SW 5th Ave., Portland, OR 97201-5528. Publisher and owner: Oregon Department of

*(Rocks, continued from page 16)*

On some collecting trips, additional equipment is desirable. Sledge hammers can be used to break especially durable ledges. Cold chisels often make it possible to loosen specimens. Dilute hydrochloric acid assists in identifying limestone and dolomite. A long list could be made of such equipment; the collector must decide for each expedition which tools are really worth the weight.

### HOUSING AND ENLARGING A COLLECTION

The practical problems of cataloging and storing a collection are ones that every collector must consider. If desired, housing arrangements can be very simple, because rocks are durable and do not require special treatment. Cigar boxes and corrugated cardboard boxes are often used. Ordinary egg cartons can be used if the specimens are rather small. Shallow wall cases for rock collections are available commercially.

It is important to have a careful system of permanent labeling, so that specimens do not get mixed. Many people paint a small oblong of white laquer on a corner of each specimen and paint a black number on the white oblong. A notebook is used to enter the number, rock name, collector's name, date collected, description of collection site, geologic formation, geologic age, and other pertinent data. If rocks are kept on separate trays, a small card containing some data is usually placed in the tray.

Extra specimens are sometimes used for trading with other collectors. Few people have the opportunity to obtain all varieties of rock types, and exchanging can fill gaps in a collection. Collectors interested in trading are usually located by word of mouth. Local rock and mineral clubs and individual collectors are numerous throughout the United States.

It may be necessary to buy some specimens, but this should be done selectively because good specimens are expensive.

### HINTS FOR ROCK COLLECTORS

1. Label specimens as they are collected. Identification can wait until later, but the place where the rocks were found should be recorded at once. Many collections have become confused because the collector did not do this.

2. Trim rocks in the collection to a common size. Specimens about 3 by 4 by 2 in. are large enough to show rock features well. Other display sizes are 2 by 3 by 1 in. or 3 by 3 by 2 in.

3. Ask for permission to collect rocks on private property. The owners will appreciate this courtesy on your part.

4. Be careful when collecting rocks. Work with another person, if possible, and carry a first aid kit. Wear protective clothing—safety glasses, hard-toed shoes, hard hat, and gloves—when dislodging, breaking up, or trimming specimens. Avoid overhanging rock and the edges of steep natural or quarried walls.

5. Do not collect rocks in national parks and monuments or in state parks, where it is illegal to do so. Similar rocks commonly crop out on land nearby and can be collected there.

6. Look for unusual rocks in large buildings or in cemeteries. Dimension stone blocks and monument stone are often transported long distances from where they are quarried. Polished stone sometimes looks different from unpolished rock. This provides good identification practice.

7. Join a mineral club or subscribe to a mineral magazine. They occasionally discuss rocks. □

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VOLUME 51, NUMBER 2

MARCH 1989



## THE GRANDEUR OF CONCRETE: PART I

*Also in this issue:*

MINING ACTIVITY AND EXPLORATION, 1988

OIL AND GAS EXPLORATION AND DEVELOPMENT, 1988





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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 DOGAMI.

## COVER PHOTOS

These photos of concrete structures in Oregon were made available to us by the Oregon Concrete and Aggregate Producers Association (OCAPA). Clockwise, from top left: One Financial Center building in downtown Portland, Oregon (Photo by Strode Eckert Photographic); Portland Center for the Performing Arts; interior of the State of Oregon Revenue Building in Salem; the Marquess Castle, a private residence in Creswell, Oregon.

## OIL AND GAS NEWS

### Mist Gas Field map revised

The map of Mist Gas Field published by the Oregon Department of Geology and Mineral Industries (DOGAMI) is now available with all 1988 changes included. Among these changes is the addition of 13 wells drilled by ARCO in the field and 5 service wells drilled by Oregon Natural Gas Development for its gas-storage project. The map is published at a scale of 1:24,000 as DOGAMI Open-File Report O-89-2 and sells for \$5.00.

### 1989 legislation

DOGAMI is sponsoring legislation during the 1989 regular session of the Legislature including one bill related to oil and gas, HB-2089. This bill would give DOGAMI authority to write rules to oversee drilling of shallow holes such as seismic-shot holes, which are currently not covered in the law. No data derived from such holes would be collected, however. There is a strong movement to protect ground water in the state, and DOGAMI feels that such a program is best placed in this Department. The purpose of the bill is to provide for such ground-water protection and for surface cleanup. Once this legislation is adopted during the 1989 session, DOGAMI will initiate rulemaking for HB-2089, including public input. □

## Forum on the Geology of Industrial Minerals to be held in Portland

The Twenty-Fifth Forum on the Geology of Industrial Minerals will be held at the Portland Center Red Lion Inn in Portland from April 30 to May 2, 1989. The Forum, which meets annually to share information on the geology of industrial minerals, has met all over the United States but until this year has never met in the Pacific Northwest. For that reason, the industrial minerals of this region will be highlighted during the Forum.

Topics to be addressed during the day and a half of paper presentations include Oregon perlite, emery, talc, limestone, and bentonite; Washington olivine; Idaho garnet and perlite; Northwest diatomite, zeolite, and pozzolan; playa resources; and state and provincial summaries, including Oregon, Washington, Idaho, Montana, and British Columbia.

Following the sessions in Portland, a three-day field trip by bus has been planned to showcase the industrial mineral resources of Oregon. Overnight stops are planned for Baker, Ontario, and Bend.

For additional information on the Forum, contact Ron Geitgey, Oregon Department of Geology and Mineral Industries, phone (503) 229-5580. □

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# Mining activity and exploration in Oregon, 1988

by Mark L. Ferns, Baker Field Office, Oregon Department of Geology and Mineral Industries

## INTRODUCTION

The pace of exploration and mining activity continued to increase in 1988. Preliminary estimates by the U.S. Bureau of Mines place the value of 1988 nonfuel mineral production at \$169 million, an increase of \$9 million from 1987. Total mineral production including natural gas was over \$175 million.

Over 605 mine sites were active during 1988. The majority, about 575, were sand-and-gravel and crushed-stone operations. The rest were industrial-mineral and small precious-metal mines.

Precious-metal exploration programs continued to increase in 1988. Over 40 companies were actively searching for gold deposits in the State. The main area of interest continued to be the Basin and Range Province in southeastern Oregon, including Malheur County, where over 5,000 new claims were staked in 1988.

## PRODUCTION

Industrial minerals continued to be an important part of the State's mineral industry. Ash Grove Cement West (active mine site 6) continued to produce crushed agricultural limestone and cement at the Durkee plant in Baker County. Ash Grove is the second-largest payer of property tax in the county and currently employs about 100 people.

Eagle-Picher Minerals, Inc., continued production of filter-grade diatomite at its facility in Malheur County. Diatomite for the plant is mined from Miocene lake sediments along the Malheur-Harney County line.

OREGON'S MINERAL PRODUCTION				
MILLIONS OF DOLLARS				
ROCK MATERIALS	METALS & INDUSTRIAL MINERALS	NATURAL GAS	TOTAL	
Sand & Gravel, Stone	Cement, Nickel, Pumice, etc.			
1972	54	22	0	76
1973	55	26	0	81
1974	75	29	0	104
1975	73	33	0	106
1976	77	35	0	112
1977	74	35	0	109
1978	84	44	0	128
1979	111	54	+	165
1980	95	65	12	172
1981	85	65	13	163
1982	73	37	10	120
1983	82	41	10	133
1984	75	46	8	129
1985	91	39	10	140
1986	96	30	9	135
1987	102	52	6	160
1988	114	55	6	175

Summary of mineral production in Oregon for the last 17 years. Data for 1988 derived from U.S. Bureau of Mines annual preliminary mineral-industry survey and Oregon Department of Geology and Mineral Industries natural-gas production statistics.

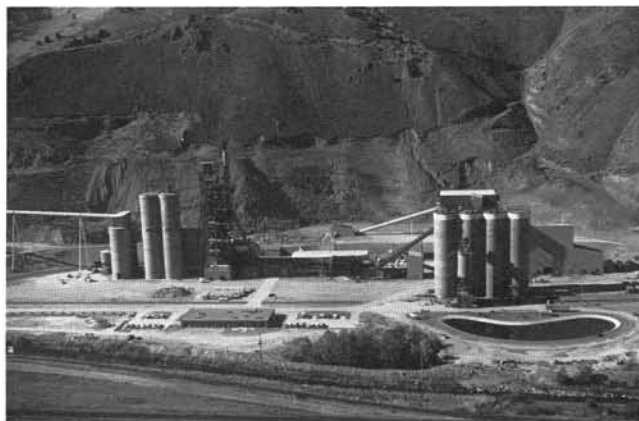
Precious-metal production continued to be small, coming mainly from small placer mines in southwestern and northeastern Oregon. The main producer was again the Bonanza Mine (active mine site 7) on Pine Creek near Halfway in Baker County.



Dry-land dredge plant in operation at Bonanza Mine (active mine site 7) in Baker County.

Table 1. Active mines in Oregon, 1988

Map no.	Name	Location	Commodity	Comments
1	Pyx Mine	Sec. 1 T. 10 S., R. 35 E. Grant County	Lode gold	—
2	Lower Grandview Mine	Sec. 6 T. 14 S., R. 37 E. Baker County	Lode gold	—
3	Pine Creek area	T. 12 S., R. 38 E. Baker County	Placer gold	—
4	Dooley Mountain area	Tps. 11, 12 S. R. 40 E. Baker County	Perlite	—
5	Clarks Creek area	Sec. 12 T. 13 S., R. 41 E. Baker County	Placer gold	—
6	Ash Grove Cement West	Sec. 11 T. 12 S., R. 43 E. Baker County	Crushed limestone and cement	Yearly production estimated at over \$25 million. Employs around 100 people.
7	Bonanza Mining Co.	Sec. 3 T. 7 S., R. 45 E. Baker County	Placer gold	Largest placer mine in Oregon with over 20 employees.
8	Cascade Pumice/Central Oregon Pumice	T. 17, 18 S. R. 11 E. Deschutes County	Pumice	—
9	Ctrl. Oregon Bentonite Co./Oreg. Sun Ranch, Inc.	Both sec. 4 T. 19 S., R. 21 E. Crook County	Bentonite clay	—
10	Oil-Dri Production Co.	Secs. 14, 21, 23 T. 27 S., R. 16 E. Lake County	Diatomite	—
11	Eagle-Picher Minerals, Inc.	Tps. 19, 20 S. Rs. 35, 36, 37 E. Harney/Malheur Counties	Filter-grade diatomite	Employs around 30 people.



Limestone quarry (background) and cement plant of Ash Grove Cement West, Inc., located south of Durkee, Baker County (active mine site 6).

Table 1. Active mines in Oregon, 1988—continued

Map no.	Name	Location	Commodity	Comments
12	Teague Mineral Products	Secs. 8, 28, 29 T. 23 S., R. 46 E. Malheur County	Bentonite clay and clinoptilolite zeolite	—
13	CooSand Corporation	Sec. 34 T. 24 S., R. 13 W. Coos County	Silica sand	—
14	Coyote Creek area	Sec. 24 T. 33 S., R. 6 W. Josephine County	Placer gold	—
15	Lower Grave Creek area	Secs. 31, 32 T. 33 S., R. 7 W. Josephine County	Placer gold	—
16	Galice area	Tps. 34, 35 S. R. 8 W. Josephine County	Placer gold	—
17	Josephine Creek area	Tps. 38, 39 S. R. 9 W. Josephine County	Placer gold	—
18	Sucker Creek area	Tps. 39, 40 S. Rs. 6, 7 W. Josephine County	Placer gold	—
19	Jones Marble	Sec. 31 T. 38 S., R. 5 W. Josephine County	Limestone	—
20	Bristol Silica and Lime Co.	Sec. 30 T. 36 S., R. 3 W. Jackson County	Silica	—
21	Steatite of Southern Oregon	Secs. 10, 11 T. 41 S., R. 3 W. Jackson County	Soapstone	—

## EXPLORATION

Exploration for precious metals, mainly gold, continued on an upswing in 1988. Over 40 companies were searching for the yellow metal by year's end.

The main area of interest in late 1988 was the Vale-Weiser area in northern and central Malheur County. This area, which lies at the intersection of the northern Basin and Range Province and the western edge of the Snake River Plain, is emerging as a highly promising epithermal-gold province.

A "rush" was triggered when Atlas Corporation announced a major discovery at its Grassy Mountain prospect (exploration site 20) south of Vale. Published geologic gold reserves are over 1 million oz at an average grade of 0.065 oz per short ton. The deposit is an epithermal (hot-springs-type) system in middle Miocene arkosic sandstones. Despite heavy snows, Atlas continued an extensive drilling program through the winter and completed more than 70 reverse-circulation holes by mid-November.

Much of the region adjacent to Grassy Mountain is undergoing extensive exploration. Other active prospects near Vale include Hope Butte (exploration site 14), Kerby (exploration site 15), Vale Buttes (exploration site 16), Double Mountain (exploration site 17), Harper Basin (exploration site 18), Shell Rock Butte (exploration site 19),

(Continued on page 31)

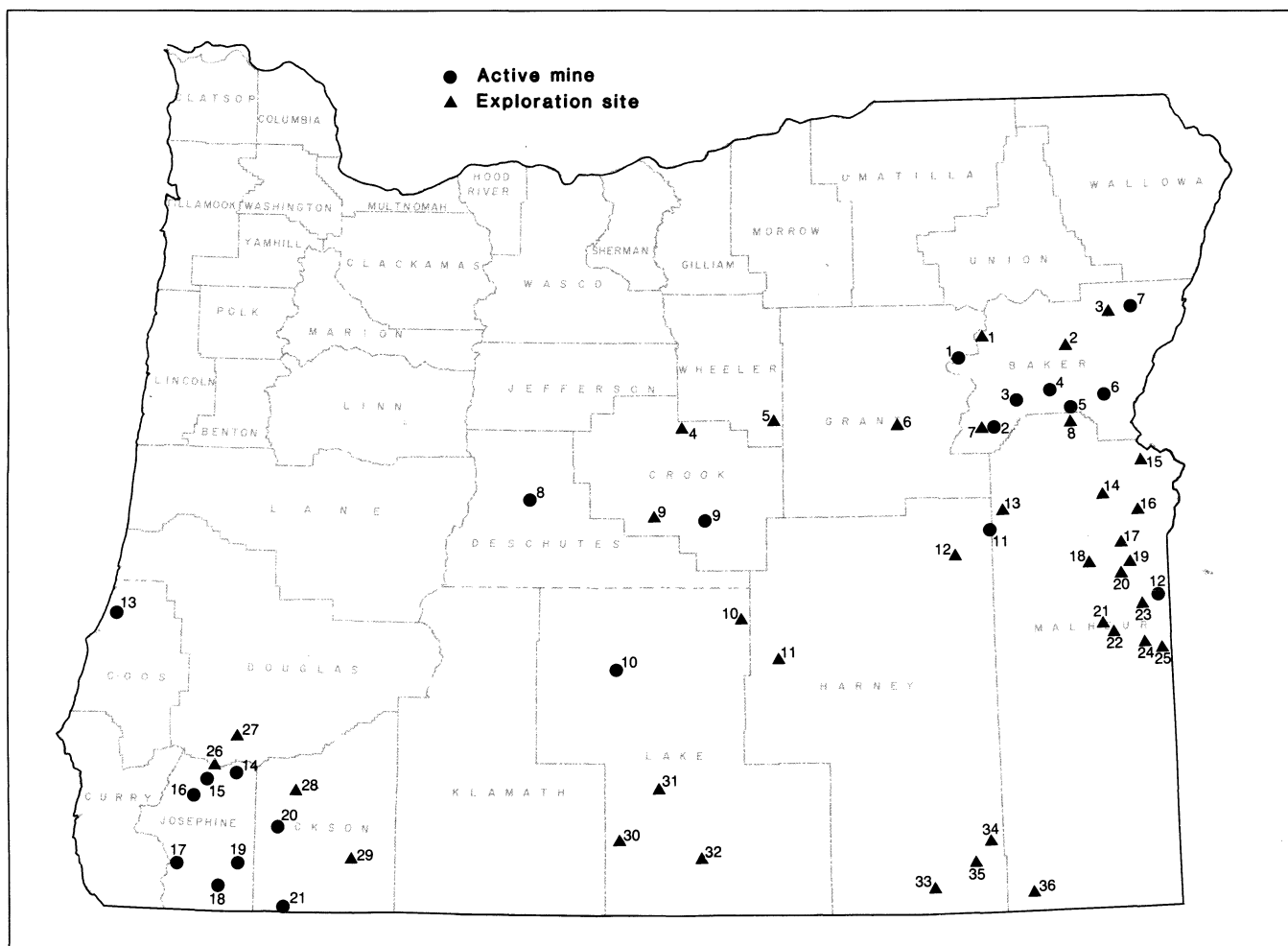
Table 2. *Exploration sites and areas in Oregon, 1988*

Map no.	Name	Location	Commodity	Comments
1	Herculean Mine	Sec. 22 T. 8 S., R. 36 E. Baker County	Gold and base metals	Small exploration and development program by Cable Cove Mining Co.
2	Virtue Mine	T. 9 S., R. 41 E. Baker County	Gold	Drill programs by Hecla at the Flagstaff and by Morris & Knudson at the Gray Eagle and Rachel.
3	East Eagle Mine	Secs. 19, 30 T. 7 S., R. 44 E. Baker County	Gold	COMINCO American continuing small exploration program.
4	Ochoco Mine	Secs. 29, 30 T. 13 S., R. 20 E. Crook County	Gold	Continued exploration by Orbana.
5	Spanish Gulch	T. 13 S., R. 25 E. Wheeler County	Gold	Evaluation program by ASARCO.
6	Prairie Diggings prospect	Sec. 33 T. 13 S., R. 32 E. Grant County	Gold	Evaluation program by Goldsearch.
7	Record Mine	Secs. 1, 2 T. 14 S., R. 36 E. Baker County	Gold	Exploration program by ICAN.
8	Malheur City area	T. 13 S., R. 41 E. Malheur County	Gold	Exploration programs by ICAN and Goldsearch.
9	Bear Creek area	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Exploration and drilling program by Freeport-McMoran.
10	Glass Buttes	T. 24 S., R. 23 E. Lake County	Gold	Drilled and later dropped by Galactic.
11	Wagontire	Tps. 26, 27 S. R. 25 E. Harney County	Gold	Under evaluation by Cal-Ore Exploration Ventures.
12	Drewsey area	Tps. 20, 21 S. Rs. 34, 35 E. Harney County	Gold	Exploration and evaluation programs by Corona Gold and Reserve Industries.
13	Castle Rock	Secs. 8, 9 T. 18 S., R. 37 E. Malheur County	Gold	Under evaluation by Chevron.
14	Hope Butte	Sec. 21 T. 17 S., R. 43 E. Malheur County	Gold	Drilling program by Chevron.
15	Kerby	Secs. 22, 27 T. 15 S., R. 45 E. Malheur County	Gold	Intensive drilling program by Malheur Mining Co. Feasibility studies underway.
16	Vale Buttes	Secs. 28, 29 T. 18 S., R. 45 E. Malheur County	Gold	Under evaluation by Atlas.
17	Double Mountain	T. 20 S., R. 44 E. Malheur County	Gold	Three reverse-circulation holes drilled by Atlas.
18	Harper Basin	T. 21 S., R. 42 E. Malheur County	Gold	Exploration program by ACNC.

Table 2. *Exploration sites and areas in Oregon, 1988—continued*

Map no.	Name	Location	Commodity	Comments
19	Shell Rock Butte	T. 21 S. Rs. 44, 45 E. Malheur County	Gold	Under evaluation by ASARCO.
20	Grassy Mountain	Sec. 8 T. 22 S., R. 44 E. Malheur County	Gold	Major discovery announced by Atlas.
21	Quartz Mountain	Sec. 6 T. 25 S., R. 43 E. Malheur County	Gold	Drilling program by Chevron.
22	Red Butte	T. 25 S., R. 43 E. Malheur County	Gold	Sampling program by Chevron.
23	Katey	Tps. 23, 24 S. R. 45 E. Malheur County	Gold	Drilling program by Manville.
24	Bannock prospect	Sec. 11 T. 26 S., R. 45 E. Malheur County	Gold	Under evaluation by Chevron.
25	Mahogany prospect	Secs. 25, 26 T. 26 S., R. 46 E. Malheur County	Gold	Drilling program by Chevron.
26	Goff Mine	Secs. 20, 29, 30 T. 33 S., R. 7 W. Josephine County	Gold, silver, copper	Continued evaluation program by Amelco/BP America.
27	Silver Peak Mine	Sec. 23 T. 31 S., R. 6 W. Douglas County	Gold, silver, copper	Drilling program by Formosa.
28	Shamrock Mine	Sec. 19 T. 34 S., R. 2 W. Jackson County	Gold, silver, copper, platinum	Exploration programs by Freeport and Boise Cascade.
29	Shale City	T. 38 S., R. 2 E. Jackson County	Gold	Drilling program by Boise Cascade.
30	Quartz Mountain	Secs. 26, 27, 34, 35 T. 37 S., R. 16 E. Lake County	Gold	Feasibility studies underway; evaluation of leach tests and engineering studies.
31	Paisley area	T. 34 S. Rs. 18, 19 E. Lake County	Gold	Joint-venture exploration program by Dergstrom and Inland Gold & Silver Corp.
32	Salt Creek	T. 38 S., R. 21 E. Lake County	Gold	Drilling program by FMC.
33	Pueblo Mountains area	Tps. 39, 40, 41 S. Rs. 34, 35 E. Harney County	Gold	Exploration programs by Lake Fork and Red Arrow Resources.
34	Whitehorse area	T. 37 S., R. 36 E. Harney County	Gold	Exploration program by Pegasus.
35	Flagstaff Butte	T. 38, 39 S. R. 37 E. Harney County	Gold	Exploration program by Geomex Minerals.
36	McDermitt area	Tps. 40, 41 S. R. 40 E. Malheur County	Gold	Exploration program by McDermitt Mines JV.





## EXPLANATION

### ACTIVE MINES

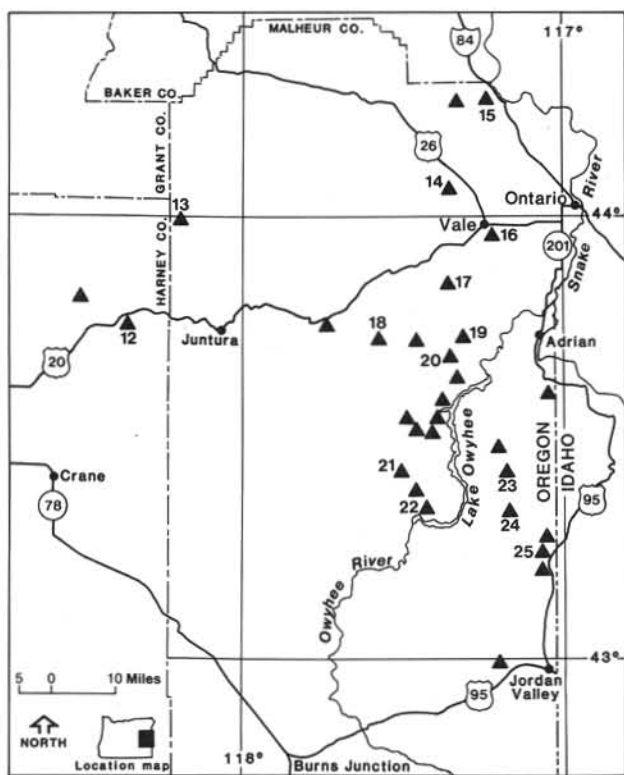
1. Pyx Mine (lode gold)
2. Lower Grandview Mine (lode gold)
3. Pine Creek area (placer gold)
4. Dooley Mountain area (perlite)
5. Clarks Creek area (placer gold)
6. Ash Grove Cement West (limestone, cement)
7. Bonanza Mining Co. (placer gold)
8. Cascade Pumice/Central Oregon Pumice (pumice)
9. Central Oregon Bentonite Co./Oregon Sun Ranch, Inc. (bentonite clay)
10. Oil-Dri Production Co. (diatomite)
11. Eagle-Picher Minerals, Inc. (filter-grade diatomite)
12. Teague Mineral Products (bentonite clay, clinoptilolite zeolite)
13. CooSand Corporation (silica sand)
14. Coyote Creek area (placer gold)
15. Lower Grave Creek area (placer gold)
16. Galice area (placer gold)
17. Josephine Creek area (placer gold)

18. Sucker Creek area (placer gold)
19. Jones Marble (limestone)
20. Bristol Silica and Lime Co. (silica)
21. Steatite of Southern Oregon (soapstone)

### EXPLORATION SITES AND AREAS

1. Herculean Mine (gold, base metals)
2. Virtue Mine (gold)
3. East Eagle Mine (gold)
4. Ochoco Mine (gold)
5. Spanish Gulch (gold)
6. Prairie Diggings prospect (gold)
7. Record Mine (gold)
8. Malheur City area (gold)
9. Bear Creek area (gold)
10. Glass Buttes (gold)
11. Wagontire (gold)
12. Drewsey area (gold)
13. Castle Rock (gold)
14. Hope Butte (gold)
15. Kerby (gold)
16. Vale Buttes (gold)
17. Double Mountain (gold)
18. Harper Basin (gold)
19. Shell Rock Butte (gold)
20. Grassy Mountain (gold)
21. Quartz Mountain (gold)
22. Red Butte (gold)
23. Katey (gold)
24. Bannock prospect (gold)
25. Mahogany prospect (gold)
26. Goff Mine (gold, silver, copper)
27. Silver Peak Mine (gold, silver, copper)
28. Shamrock Mine (gold, silver, copper, platinum)
29. Shale City (gold)
30. Quartz Mountain (gold)
31. Paisley area (gold)
32. Salt Creek (gold)
33. Pueblo Mountains area (gold)
34. Whitehorse area (gold)
35. Flagstaff Butte (gold)
36. McDermitt area (gold)

Mining and mineral exploration in Oregon in 1988 (excluding sand and gravel and stone). Active mines are keyed to Table 1; exploration sites and areas are keyed to Table 2.



Map showing locations of exploration sites for epithermal gold in the Vale-Weiser area. Numbered sites are keyed to Table 2.

Quartz Mountain (exploration site 21), Red Butte (exploration site 22), Katey (exploration site 23), and Mahogany (exploration site 25). A number of additional prospects had been located by year's end (see location map of Vale-Weiser area). These include both middle Miocene sediment- and volcanic-hosted Basin and Range systems and early Pliocene systems related to development of the Snake River Plain.

The geology is complex in this part of Oregon, from which precious metals have not been previously produced. Geologists of the Oregon Department of Geology and Mineral Industries (DOGAMI), the U.S. Geological Survey, and Portland State University are currently conducting mapping programs to generate 1:24,000-scale geologic maps of the region.

DOGAMI has published maps of two quadrangles: Owyhee Ridge (GMS-53) and Graveyard Point (GMS-54). Publication is in progress on two more quadrangles: Owyhee Dam (GMS-55) and Adrian (GMS-56). Preliminary, unedited versions of the Grassy Mountain and Double Mountain quadrangles (GMS-57 and GMS-58, respectively) are available for inspection at the DOGAMI offices in Baker, Grants Pass, and Portland, and final versions of these two maps will be published later this year.

Elsewhere in the state, Tertiary volcanic-hosted epithermal systems continued to be the main focus of exploration. Areas of interest include south-central and central Oregon. Quartz Mountain Gold Corporation continued to reevaluate its Quartz Mountain prospect (exploration site 30) in Lake County. Metallurgical testing continued on samples from the property, which is reported to contain a resource of 10 to 15 million tons grading 0.04 oz of gold per ton. The company put down 50 drill holes in 1988 to obtain samples for further metallurgical testing.



Reverse-circulation drill site at the Grassy Mountain prospect of Atlas Corporation (exploration site 20), the area from which Atlas announced a major discovery in 1988.



*Aerial view of exploration area at Grassy Mountain prospect of Atlas Corporation (exploration site 20).*



*Drill rig of Malheur Mining Company at its Kerby site (exploration site 15).*

Volcanogenic sulfide deposits in the older pre-Tertiary terranes of northeastern and southwestern Oregon continued to attract interest. Main areas of exploration continue to be the Goff (exploration site 26) and Silver Peak (exploration site 27) Mines in southwestern Oregon. Quartz veins in pre-Tertiary rocks also continued to be of some interest. Serpentine-associated systems in northeastern Oregon, such as Spanish Gulch (exploration site 5), the Prairie Diggings prospect (exploration site 6), the Record Mine (exploration site 7), and the Malheur City area (exploration site 8) drew the most attention last year.

The search for industrial minerals also continued in 1988. Perlite and diatomite were again of dominant interest to the exploration industry. Other sought-after commodities included bentonite clay, zeolite, and talc.

In July 1988, the Oregon Department of Geology and Mineral Industries published a comprehensive study of talc in Oregon (DOGAMI Special Paper 18). Similar reports on bentonite (Special Paper 20) and limestone (Special Paper 19) are scheduled for publication this spring and later this year, respectively. □

## **Send us your announcements**

One of our Medford readers has suggested that *Oregon Geology* serve as a clearing house for announcements on geological training sessions, workshops, or seminars for the professional geologist.

We think that is a good idea. So if you send us notices of your meetings and training sessions, we will print them in *Oregon Geology*, space permitting. Allow at least a month and a half—and preferably two months—lead time. □

# Oil and gas exploration and development in Oregon, 1988

by Dennis L. Olmstead, Petroleum Engineer, and Dan E. Wermiel, Petroleum Geologist, Oregon Department of Geology and Mineral Industries

## ABSTRACT

Oil and gas lease activity made a poor showing in 1988, but drilling was up 37 percent over 1987. One County, one State, and one Federal lease sale were held during the year, but a combined total of only 27,672 acres was taken at the three sales.

Mist Gas Field and vicinity had 13 wells and three redrills by ARCO Oil and Gas Company. Seven of the ARCO wells were successful, for a cumulative flow rate of 5.0 million cubic feet per day (MMcfd). The field now has fourteen producers making 9.1 MMcfd. Production value for the year was \$6.4 million. ARCO also drilled a deep test in Morrow County.

Oregon Natural Gas Development Company drilled five gas-storage service wells at Mist to complete the drilling on their two-pool storage project. Surface-equipment engineering and construction were also carried out. Gas withdrawals will begin in the fall of 1989.

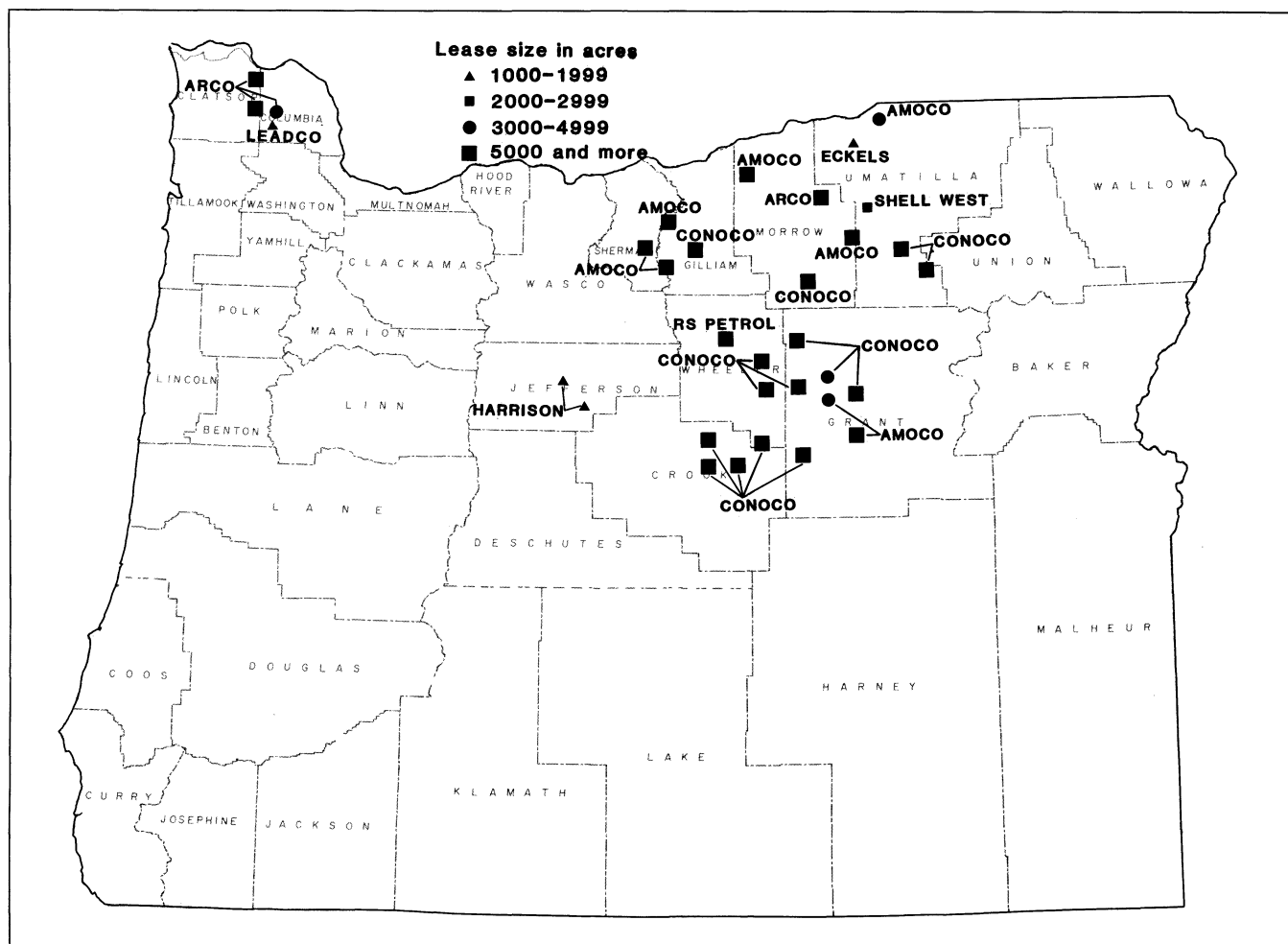
Northwest Natural Gas Company received approval to build a new 50-mi-long gas pipeline from Mist to Portland. Construction will take place in 1989.

The Department of Geology and Mineral Industries (DOGAMI) began a five-year study of the Tyee Basin in western Douglas and eastern Coos Counties. Emphasis will be on source rock, stratigraphy, and structure of the rocks in the basin.

## LEASING ACTIVITY

Leasing of public land in 1988 consisted of three public-lands lease sales plus over-the-counter leasing of Bureau of Land Management (BLM) property. The accompanying lease map shows major areas of leasing. It includes over 220,000 acres issued early in the year to Amoco and Conoco. This acreage appeared in our 1987 report because the filing dates back to December 1987.

The first lease sale of the year was held on June 16, 1988, by Columbia County. At the sale, 94 parcels were offered, comprising 32,407 acres, all in and around Mist Gas Field. Successful bidders were ARCO and Leadco, taking 29 parcels totaling 8,079 acres. The high bid was \$51 per acre in sec. 20, T. 6 N., R. 5 W. Income to the County from the sale was about \$145,000. The terms of Columbia County leases are as follows: primary term of ten years, three-sixteenths royalty, and annual rental of \$10 per acre.



Major areas of public-land leasing in 1988. Map shows acreage applied for and issued during the year. Most issued acreage is from 1986 and 1987 applications; only 5,000 acres were filed for in 1988. Withdrawals and terminations are not shown. Data courtesy of Dolores Yates, LANDATA.

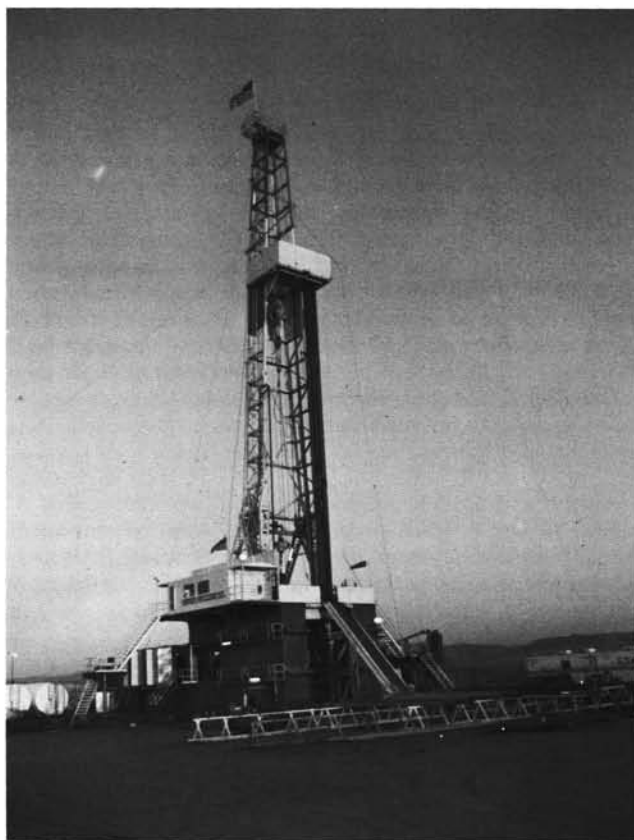


Table 1. Oil and gas permits and drilling activity in Oregon, 1988

Permit no.	Operator, well, API number	Location	Status, depth (ft) TD=total depth PTD=proposed TD RD=redrill
376	ARCO Columbia Co. 42-8-54 36-009-00213	NE¼ sec. 8 T. 5 N., R. 4 W. Columbia County	Completed, gas; TD: 2,255.
392	ARCO Longv. Fibre 32-20-65 36-009-00229	NE¼ sec. 20 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 1,249.
397	ARCO Hanna 1 36-049-00002	NE¼ sec. 23 T. 2 S., R. 27 E. Morrow County	Abandoned, dry hole; TD: 9,211.
398	ARCO CFI 34-1-55 36-009-00232	SE¼ sec. 1 T. 5 N., R. 5 W. Columbia County	Completed, gas; TD: 1,370.
399	ARCO Johnston 44-19-65 36-009-00233	SE¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,910.
400	ARCO Columbia Co. 12-19-65 36-009-00234	NW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 3,209.
401	Oregon Nat. Gas Dev. IW 42C-10 36-009-00235	NE¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,769.
402	Oregon Nat. Gas Dev. IW 22D-10 36-009-00236	NW¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,770.
403	Oregon Nat. Gas Dev. OM 43B-10 36-009-00237	SE¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,616.
404	Oregon Nat. Gas Dev. IW 33D-3 36-009-00238	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,962.
405	Oregon Nat. Gas Dev. IW 23B-3 36-009-00239	SW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,974.
406	ARCO Columbia Co. 44-27-65 36-009-00240	SE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,150.
407	ARCO Columbia Co. 24-9-64 36-009-00241	SW¼ sec. 9 T. 6 N., R. 4 W. Columbia County	Completed, gas; TD: 2,503.
408	ARCO CFW 12-15-64 36-009-00242	NW¼ sec. 15 T. 6 N., R. 4 W. Columbia County	Completed, gas; TD: 1,950.
409	ARCO Benson 14-7-64 36-009-00243	SW¼ sec. 26 T. 6 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 2,506.
410	ARCO CFI 23-16-64 36-009-00244	NW¼ sec. 16 T. 6 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 1,775.
411	ARCO Hamlin 33-17-65 36-009-00245	SE¼ sec. 17 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,835.

Table 1. Oil and gas permits and drilling activity in Oregon, 1988  
—continued

Permit no.	Operator, well, API number	Location	Status, depth (ft) TD=total depth PTD=proposed TD RD=redrill
412	ARCO, Longview Fibre 32-20-65R and Redrill 36-009-00246 36-009-00246-01	NE¼ sec. 20 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 3,230, RD: 3,088.
413	ARCO Columbia Co. 22-17-75 36-009-00247	NW¼ sec. 17 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD: 3,250.
414	ARCO, Sterling 12-24-66 and Redrill 36-009-00019 36-009-00019-01	NW¼ sec. 12 T. 6 N., R. 6 W. Clatsop County	Abandoned, dry hole; TD: 3,144, RD: 2,845.
417	ARCO, Longview Fibre 24-8-75 and Redrill 36-009-00248 36-009-00248-01	SW¼ sec. 8 T. 7 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,814, RD: 3,039.
418	ARCO OR 21-33-86 36-007-00020	NW¼ sec. 33 T. 8 N., R. 6 W. Clatsop County	Permit issued; PTD: 6,000.
419	ARCO OR 13-33-86 36-007-00021	SW¼ sec. 33 T. 8 N., R. 6 W. Clatsop County	Permit issued; PTD: 6,000.



Drilling at the ARCO Hanna 1 well in the Columbia Basin, Morrow County.

BLM held a lease sale on September 7, offering 314,635 acres in 185 parcels. No bids were received, and the acreage was made available the following day for noncompetitive over-the-counter filing. Subsequently, applicants filed for four parcels consisting of 4,335 acres in central Oregon, at a total fee and rental cost of \$6,802.

During 1988, several changes took place in the way BLM conducted its leasing program. The agency made modifications in the way over-the-counter filings may be made. Additional changes last year included initiation of quarterly lease sales by BLM, with the September 7 sale being the first on this schedule. Subsequent sales were scheduled for January 25 and March 1, 1989. The January 25 sale received no bids, while results of the March 1 sale were not available in time for this report. The 1988 rental income for Federal leases totaled \$1,139,822, and at year's end, 876,135 acres in 397 parcels were under lease, an increase of 15 percent in leased acreage over the previous year.

The Oregon Division of State Lands held a lease sale on November 1, 1988, offering 19,553 acres in 43 parcels, mainly in Clatsop County. Successful bidders included ARCO (15,553 acres), and W. Cooper (3,200 acres). L. Fisk also took 800 acres in Wheeler County with no bidding. These leases were issued December 7, 1988. Fees and bonus payments totaled about \$75,000 to the State.

Terminated Federal and State lease acreage totaled 324,535 acres.

## DRILLING

Fourteen exploratory oil and gas wells, five gas storage wells, and three redrills were drilled in the state in 1988. This is a significant increase over the level of the 1987 drilling activity. All but one of the wells were drilled in the Mist Gas Field area, a pattern that has continued since the field was discovered in 1979. The other well was a wildcat well drilled by ARCO in the Columbia Basin of north-eastern Oregon. This well, the Hanna 1, was the first well drilled for oil and gas in Morrow County and was a rare attempt to penetrate the volcanic rocks covering this geologic province and to reach the underlying strata that are interpreted to contain favorable conditions for oil and gas accumulation and entrapment. The well was drilled to a total depth of 9,211 ft, making it the deepest well drilled in Oregon during 1988, but was plugged and abandoned as a dry hole.

At Mist Gas Field, two operators were active during the year. As has been the case for the past several years, ARCO Oil and Gas Company was the most active operator, drilling 13 exploratory wells



*Logging operations at well IW 42C-10 of Oregon Natural Gas Development Company as part of the natural-gas storage project at Mist Gas Field.*

and three redrills. Of these, seven were successful gas completions, while the rest were dry holes. Oregon Natural Gas Development Corporation, a subsidiary of Northwest Natural Gas Company, drilled five wells as part of the natural-gas storage project. Details of these wells are provided in the natural gas storage project portion of this summary.

Total footage drilled for the year, including the gas-storage wells, was 61,523 ft, a significant increase over the 42,665 ft drilled during 1987. The average depth per well was 2,797 ft, about the same as the average of 2,896 ft per well drilled the previous year.

During 1988, DOGAMI issued 21 permits to drill (Table 1), while two expired permits were canceled, and three permits were denied during the year (Table 2).

## DISCOVERIES AND GAS PRODUCTION

Mist Gas Field saw seven new producers, which ties last year's results as the record for the number of new gas wells discovered in a single year at Mist. ARCO Oil and Gas Company is the operator of all these wells, which include the CFI 34-1-55, CFW 12-15-64,

*Table 2. Canceled and denied permits, 1988*

Permit no.	Operator, well, API number	Location	Issue date	Cancellation date	Reason
356	ARCO Columbia Co. 13-21 36-009-00195	SW¼ sec. 21 T. 6 N., R. 5 W. Columbia County	3-28-86	3-28-88	Permit canceled; expired.
369	ARCO CFI 31-22 36-009-00206	NE¼ sec. 22 T. 6 N., R. 5 W. Columbia County	7-18-86	7-18-88	Permit canceled; expired.
396	Interwest Exploration Cavenham 31-5 36-007-00018	NE¼ sec. 5 T. 6 N., R. 7 W. Clatsop County	—	—	Permit denied; incomplete application.
415	ARCO Greenup 1 36-049-00003	NE¼ sec. 19 T. 2 S., R. 28 E. Morrow County	—	—	Permit denied; operator withdrew application.
416	ARCO Greenup 2 36-049-00004	NE¼ sec. 20 T. 2 S., R. 28 E. Morrow County	—	—	Permit denied; operator withdrew application.

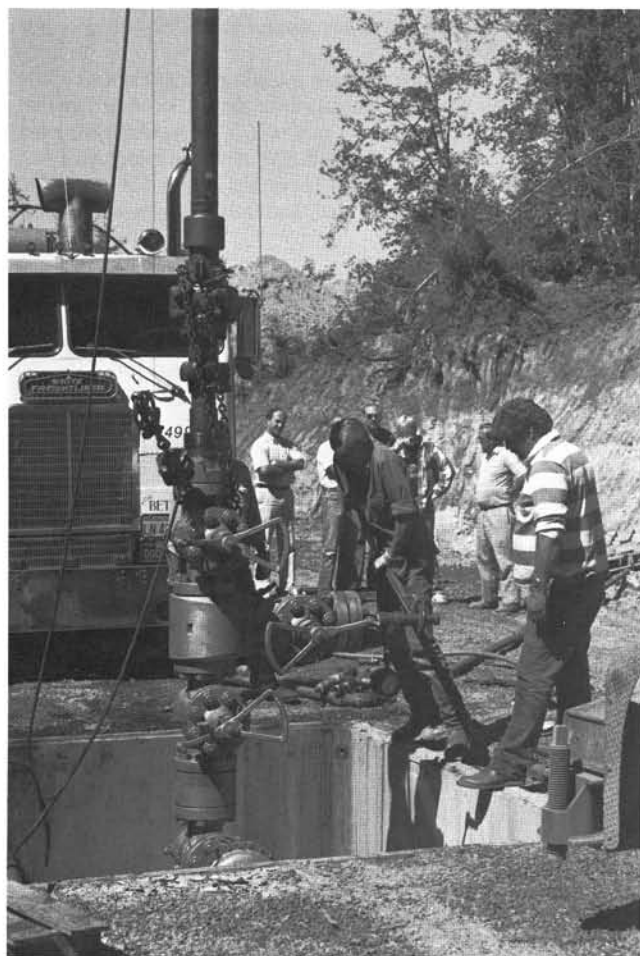
CC 12-19-65, CC 24-9-64, CC 42-8-54, CC 44-27-65, and LF 32-20-65R-RD1. Cumulative flow rate for these wells is 5.0 MMcf of gas. This brought the total number of producers in the field to 14 at year's end, with an additional six wells awaiting pipeline connection. Seven wells at the field are shut in.

Three of the seven new gas producers discovered during 1988 extend the geographic limits of established production in the Mist Gas Field: Two are now the easternmost producers in the field and are located some 4 mi from the nearest previous producers. In addition, one of the new producers is the westernmost gas well in the field and is within a quarter of a mile of the Clatsop County line.

Gas production for the year totaled 4.0 billion cubic feet (Bcf), an increase from the 3.8 Bcf produced during 1987. The cumulative field production through the end of 1988 was about 35.8 Bcf. The total value for the gas produced for the year was \$6.4 million, an increase of 16 percent over the \$5.5 million during 1987. Gas prices varied between 14 cents and 20 cents per therm.

### GAS STORAGE

Drilling for the Mist gas-storage project was completed by Northwest Natural Gas Company in 1988, adding to two previous years of storage- and monitor-well drilling. Five wells were drilled during the year—four injection-withdrawal wells and one observation-monitor well. Total footage drilled for these wells was 14,091 ft, for an average depth of 2,818 ft per well. Two of the injection-withdrawal



*Swabbing Oregon Natural Gas Development Company well IW 23B-3 at Mist Gas Field, one of the procedures preparing the well for service as an injection-withdrawal well.*

wells were added to the Flora Pool and two were added to the Bruer Pool, completing a total of three injection-withdrawal wells for each of these pools. Injection-withdrawal wells are used to add gas to and remove gas from the storage reservoir.

During 1988, the Miller Natural Gas Station was being re-designed, and the only gas injection done during the year was during February, when 4.2 MMcf of gas was injected into the Bruer Pool to test the compressors at Miller Station. Withdrawals are scheduled to begin during fall 1989. The observation-monitor well was drilled on the southern edge of the storage area, bringing to seven the total number of observation-monitor wells drilled. Observation-monitor wells are used to monitor the gas levels and pressures in the storage reservoir. No additional drilling is expected at the gas-storage project at this time.

### OTHER ACTIVITIES

DOGAMI began a five-year study of the Tyee Basin during 1988. The Tyee Basin is located in the southern Coast Range and contains Eocene sandstone strata that are believed to have similarities to the sands that produce gas at Mist Gas Field. The study area is located primarily in western Douglas and eastern Coos Counties. In the study, emphasis will be placed on those characteristics needed to generate and trap gas and oil, namely, source rock, stratigraphy, and structural framework. Funding for the study is being provided by landowners in the study area and by County, State and Federal agencies. DOGAMI will release publications reporting the results of the ongoing study to keep the public informed of its progress.

The Northwest Petroleum Association remained active during 1988, showing a membership of about 140 at year's end. At monthly meetings, papers related to the oil and gas industry were presented, and a field symposium with a geologic field trip was held in May. The 1988 symposium took place in Ocean Shores, Washington, and included field trips to the Chehalis and Grays Harbor Basins as well as the coastal area of the Olympic Peninsula.

Northwest Natural Gas received approval from the Energy Facility Siting Council to build a natural-gas pipeline from the Mist Gas Field to Portland. The pipeline, the South Mist Feeder, will be of 16-in. steel, 50 mi long, and will extend from the Mist storage project to West Union Road, west of Portland, where it will connect with existing pipeline facilities. With the new pipeline, Northwest Natural Gas Company will increase deliverability when producing or storing gas. The line will also provide a back-up capability in the event the existing gas line needs to be turned off.

Offshore oil and gas exploration is still several years away in the region, but planning is underway at the State and Federal levels. The Oregon Ocean Resources Management Task Force, established by the 1987 Legislature, met six times and released an Interim Report. Public workshops were also held to gather input on the concept of planning for new uses of the ocean, primarily mineral development. The consensus from the public was that existing uses such as fishing and tourism should be preserved, whereas mining or oil and gas exploration should be prevented. Further meetings will result in a draft plan in September 1989, followed by additional public input. A final plan is scheduled for July 1990.

Meanwhile, the U.S. Minerals Management Service is moving ahead with its plans for an April 1992 oil and gas lease sale for the outer continental shelf off Oregon and Washington. The agency held a workshop in Portland in June 1988 to gather input about its environmental studies program in preparation for the sale. Several studies are underway, and more are planned for 1989 and 1990. Industry interest will not be gathered until November 1989 and may ultimately determine whether there will be a 1992 offering.

The Mist Gas Field map (1:24,000) has been updated as DOGAMI Open-File Report O-89-2. It reflects all 1988 drilling activity in the field, including gas-storage and monitor-well activity. □



# The grandeur of concrete: Part I

by Don Dupras, Geologist, California Division of Mines and Geology

This article first appeared in the January 1989 issue of *California Geology* and is reprinted by permission here because we believe it will be of interest to our readers. It is the first of a two-part series describing how concrete is made, how it is used, and how important it is in our lives. Part I presents the history of the development of concrete, the advent of the concrete industry in America, and the composition of modern concrete. Part II will appear in a later issue and will describe our dependence on concrete and modern advances in concrete technology.

—Editor

## INTRODUCTION

Concrete literally forms the foundation of our society. Our homes, factories, offices, schools, roads, runways, dams, sewers—in short, our quality of life depends on inexpensive and abundant concrete (Figure 1). Engineers and architects utilize its versatility for thousands of specialty uses. The fire-resistant property of concrete is a structural advantage over wood; concrete does not burn or rot. Its insulating properties are widely employed to save on heating and cooling costs. The density of ordinary concrete enables it to store solar heat and to slowly release it at night. Concrete is relatively inexpensive, readily available, permanent, very durable, and easy to make; all that is needed is a mold and sufficient time for curing. As important as concrete is to our society, this triumph of human ingenuity is so commonplace that hardly anyone appreciates it.

## EARLY HISTORY

As we casually use sidewalks, roads, and swimming pools, it is easy to overlook the distinguished lineage of concrete. Cement, the principal matrix material of concrete, has been utilized for over 5,000 years. The ancient Egyptians used a cement mortar made with heated or "calcined"<sup>1</sup> gypsum in the construction of the great pyramids at Giza and other structures. Cement was used for the construction of the harbor at Kition, Cyprus, in about 600 B.C. (Stapleton, 1981; Encyclopedia Britannica, 1984).

## Mediterranean area

Lime-based cement, a significant improvement over gypsum-based cement and quite similar to the cement used today, was used by the Mycenaeans and Phoenicians in about 500 B.C. The oldest lime cement so far discovered is in the ruins of a Phoenician temple on Cyprus (Draffin, 1943). Lime cement was made by calcining limestone and then crushing it to a fine powder. Gypsum required a calcining temperature of 300 to 400 °F. In contrast, lime required a calcining temperature of 1,500 to 1,650 °F. In the early lime calcining process, heated limestone ( $\text{CaCO}_3 + \text{heat}$ ) produced carbon dioxide gas ( $\text{CO}_2$ ) and lime ( $\text{CaO}$ ). Water added to crushed lime causes a chemical reaction and results in firm hydrated lime cement [ $\text{Ca}(\text{OH})_2$ ]. When mixed with water and sand, the lime cement made a durable mortar (Lea, 1970).

The use of lime cement spread from Crete to Greece, where it was used to line hand-dug cisterns and was mixed with sand and gravel to form a primitive concrete used in construction. From Greece, the use of lime cement spread to Rome, Carthage, and other cities around the Mediterranean Sea. A problem encountered with this early lime mortar was that it gradually dissolved when exposed to rainwater (Encyclopedia Britannica, 1984).

## Roman concrete

The fame of Roman engineers as master builders is due in no small part to their use of lime cement mixed with broken tile, stone,

volcanic ash, and water to form strong, long-lasting concrete structures. The Romans greatly improved the strength and durability of concrete and were the first to use it in significant amounts. The words "cement" and "concrete" come from the Latin words *caementum*, for pieces of rough uncut stone, and *concretus*, which means to grow together. Roman masons screened and washed sand and gravel (called "aggregate"<sup>2</sup>) in preparation for use in concrete. The practice of screening and washing sand and gravel is still necessary for making sound concrete.



Figure 1. Transamerica Building, San Francisco, California. Concrete products are pervasive, and it is hard to imagine our society without them. The graceful Transamerica Building in San Francisco is one example of the varied forms and functions of concrete design. At 853 ft high, it is the second tallest building in California. Photo by Don Dupras.

<sup>1</sup> Calcining is a heating process that drives off volatile gases, such as water vapor and carbon dioxide, and makes the cement reactive with water. Calcined gypsum is partially dehydrated and is known today as plaster of Paris.

<sup>2</sup> Aggregate is a general term that refers to any hard inert material such as sand, gravel, smelter slag, or crushed rock. Strong and durable aggregate is of prime importance in cement products such as concrete, mortar, and plaster. These materials commonly contain more than 70 percent aggregate by volume.



In about 150 B.C., the Romans discovered that a glassy, fine-grained volcanic ash added to lime cement in place of sand made the concrete water-resistant and gave it superior strength. The best Roman cement was made with volcanic ash they called "pozzuolana," which was quarried near the town of Pozzuoli, Italy. The ash had been erupted from the volcano Mount Vesuvius (Hansen, 1982).

Roman pozzolan cement had the ability to harden under water. This water-resistant property is caused by silica in the volcanic ash chemically reacting with lime to form insoluble compounds in concrete. This superior cement enabled the Romans to construct resistant concrete marine facilities such as seawalls, piers, lighthouses, and breakwaters. The remains of these ancient structures can be seen today on the shores of the Mediterranean Sea (Encyclopedia Britannica, 1984). Today, cement of this type such as portland cement is termed "hydraulic cement." Pozzolan is a common admixture used in modern concrete structures, and concrete made with such hydraulic cement can be placed under water through a hose called a "tremie line."

Roman engineers were the first to use lightweight concrete in building construction. Broken pumice, a lightweight porous volcanic glass, was used as aggregate when lightweight concrete was required. Lightweight pumice concrete improved wall insulation, reduced construction weight, and was better able to withstand frost action (Stapleton, 1981).

After 2,000 years, many examples of Roman concrete remain in place and illustrate the important contribution this material has made to modern civilization. Roman engineers constructed the

world's earliest and most enduring examples of concrete architecture. The Pantheon, Colosseum, Hadrian's mausoleum, Roman baths, aqueducts, and Roman roads throughout Europe are monuments to the varied forms and functions of early concrete design. Concrete enabled the Romans to experiment with circular walls, vaulted ceilings, and domes; Roman concrete architecture still influences and inspires contemporary engineers.

The circular-domed Pantheon in Rome has survived virtually intact and is the most famous early concrete structure in the world. It was an architectural experiment and one of the first large concrete structures to incorporate lightweight aggregate concrete. The Pantheon was completed in 124 A.D. and dedicated as a religious temple. At the time, it was more than twice the size of any other domed building (Figure 2). Its 21-ft-thick circular wall is honeycombed with cast pozzolan concrete arches and sandwiched by marble veneer (Norwich, 1978; Mark, 1987).

Although the wall is an engineering feat in itself, the most interesting aspect of the Pantheon is its dome. The dome is 143 ft in diameter, 4 ft thick at the center, and incorporates nearly 5,000 yd<sup>3</sup> of poured pozzolan concrete (Hansen, 1982). The base of the dome was made with normal sand and gravel aggregate for strength, because concrete strength is lost when lightweight aggregate is used. As the builders approached the top of the dome, they used lighter and lighter aggregate in the concrete until at the center, only pumice aggregate was used. The Pantheon is the only Roman building with its dome still intact (Stapleton, 1981).

The Roman Colosseum, a limestone, mortar, and concrete stadium, was completed in 80 A.D. and could accommodate 60,000 people. The word "colossal" is derived from the Latin word meaning huge. The Colosseum included miles of barrel-vaulted and groin-vaulted concrete passageways that provided smooth movement for the crowds. The foundation was built with 40-ft-deep concrete pilings.

Many other large Roman public works such as aqueducts, mausoleums, and sewer systems were constructed with cement mortar and concrete. One example of this type of construction is the extensive Cloaca Maxima sewer system beneath the streets of Rome. Another example is the graceful Roman aqueduct near Nimes, France, which was completed in 18 B.C. The portion of the 24-mile-long aqueduct that crosses the river, called the Pont du Gard, still stands and is 155 ft high. The top level supports a mortared water conduit 4 ft wide and 5 ft high (Stapleton, 1981).

The illustrious Roman road system that connected the empire had nearly 54,000 mi of highways and another 200,000 mi of connected roads. Engineers provided adequate drainage and carefully surveyed highway routes for directness between towns. Commonly, these highways were 4 ft thick and layered, with sand and gravel at the base, concrete in the middle, and stone blocks at the surface. The rigid roadbeds normally lasted 30 to 40 years without repairs. Several of these roads lasted for hundreds of years after the fall of the Roman Empire—even without repairs (Stapleton, 1981; Weisburd, 1988).

The technology of making high-quality, sound concrete declined after the fall of the Roman Empire. The low point of inferior concrete design in Europe occurred between the 9th century and the 11th century, when the practice of using sufficient heat to calcine limestone was abandoned. During the 12th and 13th centuries, proper calcining temperatures were again initiated, and the quality of cement gradually improved. By the end of the 1500's, pozzolan materials were again used in concrete mixtures. Concrete development progressed very slowly from that period until the Industrial Revolution (Lewis, 1981).

By the 1700's, engineers throughout Europe were experimenting with various natural cementitious materials that included limestone, limy mud, gypsum, pozzolan ash, oyster shells, diatomaceous earth, and chalk. Because the ingredients in these "natural cements" varied widely, and because procedures for making concrete were often haphazard, the quality of concrete structures made in the 1700's was erratic.



Figure 2. The Pantheon, Rome, Italy. The entrance portico inscription, "M. AGGRIPPA. L.FCOS. TERTIVM. FECIT" (Latin for "Marcus Agrippa, son of Lucius and three times consul, built this"), refers to an earlier rectangular temple that was built on this site about 25 B.C. and later destroyed by fire. The domed Pantheon was added to the portico in 124 A.D. and dedicated to the seven major Roman gods. It is unique not only for its innovative concrete architecture but also because it is one of the very few buildings of Imperial Rome that have remained intact—a testament to solid concrete design. The large interior drum-shaped room has inlaid marble floors and is covered by a poured concrete dome 143 ft in diameter that was not exceeded in size until the mid-1800's. The dome has a 30-ft-wide oculus or round opening in the top to illuminate the interior. The 21-ft-thick walls are not solid concrete but are honeycombed with concrete arches. The Pantheon is one of the first large concrete buildings and still serves as an architectural model for other domed buildings. This and following photos courtesy of the Portland Cement Association except as noted.

It should be noted that natural cements are still used, mainly in nonindustrial countries, and make fairly durable concrete structures. Natural cements have less durability, are less versatile, and harden faster than portland cement. However, some have remarkable compressive strength of 11,000 lb per in<sup>2</sup> (Draffin, 1943).

## PORTLAND CEMENT

The Industrial Revolution in England caused a serious shortage of timber for the building trades. During that time, there was an intense demand for canals, factories, harbors, and other structures. Builders sought to reduce their dependence on wood structures by using increasing amounts of mortar, brick, and concrete.

In 1757, civil engineer John Smeaton was hired to design and build the Eddystone Lighthouse off the coast of Plymouth, England. After conducting several experiments to determine what cementing materials would set and remain stable under seawater, he chose a mixture of calcined argillaceous limestone from the Isle of Portland and pozzolan ash brought in from Italy. His studies showed that the best cement could be made from limestones that had the highest clay content. The concrete proved to be exceptional, and the Eddystone Lighthouse lasted for 126 years before it was replaced. Smeaton is said to have rediscovered the Roman pozzolan cement formula by examining an old Roman document (Skinner, 1976).

### Joseph Aspdin

Nearly all concrete used today incorporates portland cement. The credited inventor of this exceptional cement was Joseph Aspdin, a brick layer and mason from Leeds, England. After much experimentation, Aspdin developed the process of carefully proportioning limestone and clay collected from local quarries, pulverizing it, and heating the mixture on his kitchen stove. He then ground the compound into a fine powder. The resulting hydraulic cement made a very strong and durable concrete when mixed with the proper proportions of water and aggregate. Joseph Aspdin named it "portland cement" because the limestone he used was quarried on the nearby English Isle of Portland (Figures 3-5) (Legget and Karrow, 1983).

Aspdin took out a patent on his portland cement in 1824. Shortly thereafter, he built a small kiln that produced up to 6 tons of clinker after several days of heating (Figure 6). Aspdin later discovered that a higher calcining temperature produced a superior cement, and he secretly incorporated the heating process (Lewis, 1981). For a number of years, Aspdin's portland cement process slowly expanded.



Figure 3. Drawing of Joseph Aspdin at his workshop. He patented his process of making artificial stone in 1824 and called it "portland cement." Nearly all construction concrete used in the world today incorporates portland cement as its fundamental binding ingredient. Most portland cement used today is nearly the same as that discovered by Joseph Aspdin.



Figure 4. Aspdin's original cement plant in Wakefield, England, around 1860. The first extensive use of cement was in the Thames Tunnel in 1828. The engineer in charge of the project insisted on using portland cement and faced strong opposition because it cost more than twice as much as other natural cements then available. The cement proved worthy, and in the 1860's, nearly 70,000 tons of portland cement were used in the construction of the London sewer system. Aspdin's son William tried to keep his father's formula a secret by placing trays of copper sulfate in the kilns during the calcining process. The noticeable smell was intended to deceive competitors.

However, portland cement concrete proved to be so durable, versatile, and efficient that by the 1850's, the process for making the cement was well established in England, Germany, and Belgium.

It is generally agreed that Joseph Aspdin was not the sole inventor of portland cement, because other English inventors were also working on similar cementing materials in the region during that time. In any event, within a month after pouring, portland cement concrete developed nearly twice the compressive strength of many other natural concretes then used.

Aspdin lived to see the first bulk use of portland cement as a masonry liner in a tunnel that went under the Thames River. Portland cement today is manufactured basically the same way as Aspdin's patented process, but it is made with far greater precision and in far greater tonnages than he ever dreamed.



Figure 5. The famous limestone quarry on the Isle of Portland, south coast of England (around 1850). When Joseph Aspdin was experimenting with his cement concoctions, he had no efficient way of grinding the limestone. He found that the steel-rimmed wagons had sufficiently pulverized the limestone along the quarry road for his experiments. In 1825, while collecting crushed limestone samples along the main quarry road, he was arrested and fined for theft of public property.



Figure 6. A bottle kiln for calcining limestone used in Aspdin's cement plant (around 1850). The kiln was 36 ft high, 17 ft in diameter at the base, and had a capacity of 21 tons of limestone per burn. It was much larger than Aspdin's original kiln, which had a capacity of about 6 tons of limestone. Early kilns of this type had a natural draft. Therefore, calcining and cooling might take several days, depending on the prevailing winds.

#### U.S. portland cement

In an effort to expand their markets, European manufacturers began shipments of portland cement to the United States in 1868. To reduce freight costs, the cement was first shipped in wooden barrels<sup>3</sup> as ship ballast. Portland cement proved to be so durable and versatile that engineers in the United States soon preferred it to other natural cements then in use, and shipments increased (Figure 7). The portland cement market in the U.S. quickly spread.

David Saylor had previously worked in the manufacture of natural cement concrete and felt that he too could make Portland cement (Figure 8). In 1871, he made the first portland cement in the United States at Coplay, Lehigh Valley, Pennsylvania. Saylor found that an argillaceous limestone<sup>4</sup> in that valley contained the proper proportions of ingredients needed to make quality portland cement. Like Smeaton and Aspdin, Saylor systematically studied the physical properties of cement and concrete to improve it. His operation was a success, and his company prospered.

There was a strong demand for cement to accompany the rapid American industrialization during the 1870's and 1880's. Large engineering projects such as the Erie Canal, factories, sewer systems, and bridges fostered the spread and manufacture of portland cement in the United States.

<sup>3</sup> Cement is purchased and measured by weight because its volume changes due to compaction. The concrete industry still measures cement in barrels, a practice that dates back to the mid-1800's, when it was shipped in barrels. By definition, a barrel weighs 376 lb and contains four bags that are 94 lb each. A bag of cement is roughly 1 ft<sup>3</sup>.

<sup>4</sup> Argillaceous limestone is common and contains as much as 50 percent clay minerals. This natural "cement rock," as it is sometimes known, needs few additional materials to make good cement. An argillaceous limestone that would make a good portland cement would contain 50 to 65 percent lime, 10 to 20 percent silica, and 15 to 35 percent clay minerals, including alumina and iron oxide.



Figure 7. An early shipment of portland cement in wooden barrels to the United States during the 1860's. Large quantities of natural cements were used in the United States during the early 1800's. Engineers began to switch to portland cement when they realized its superior performance.

#### Rotary kiln

By the mid-1880's, the demand for portland cement products was rapidly growing, but the process of making it was labor intensive and time consuming. It proved to be difficult to mass produce, and rows of large vertical brick kilns were constructed to meet the demand. Cement made in these kilns required a great deal of heat for calcining the limestone. After the calcining process, the mixture was allowed to cool and was removed for processing. The cooling process was dependent on wind conditions and commonly took several days. The process of manufacturing portland cement in vertical kilns was costly and inefficient.

Frederick Ransome, an English engineer and inventor, revolutionized the building industry by making it possible to mass produce portland cement. In 1885, Ransome patented a slightly inclined



Figure 8. David Saylor, the first American to produce portland cement at Coplay, Pennsylvania. As a manufacturer of natural cement, Saylor became convinced that portland cement produced a superior concrete. After experimenting with a local argillaceous limestone in 1871, he began producing high-quality portland cement in bottle kilns he had built from English design. By 1876, Saylor's cement was accepted and recommended for use by the United States Engineer's Office.



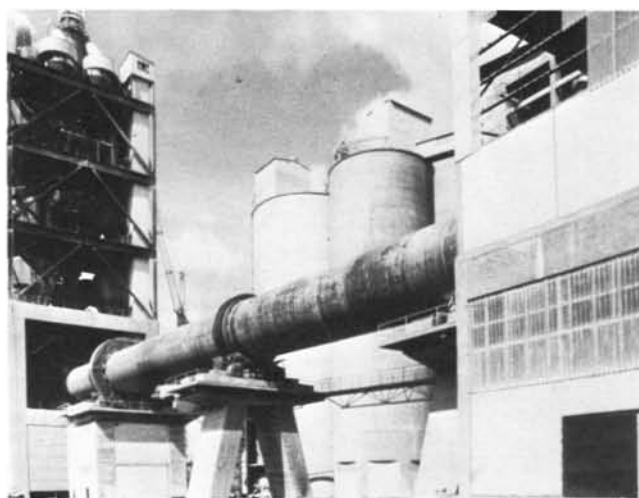


Figure 9. A modern rotary kiln. The kiln is about 500 ft long and 14 ft in diameter. It is made of steel, lined with firebrick, and rotates around giant roller bearings about one complete turn a minute. Raw materials for portland cement are fed into the kiln at the right, gradually travel down the kiln to the left as it rotates, and are steadily heated to a temperature of about 2,700 °F. The gases produced by the calcining process are collected in the building at the left. For a kiln of this size, it takes about three hours for the materials to make a complete passage.

cylindrical kiln that slowly rotated. Crushed raw material could be continuously added at the top of the rotating kiln, calcined, and then removed. Early rotary kilns developed several problems that took years to remedy. Regardless of these problems, the invention of the rotary kiln is comparable to the development of the Bessemer process for making steel. Rotary kilns dramatically increased output, decreased costs, and improved the uniform quality of portland cement (Figure 9).

Thomas Alva Edison (Figure 10) was instrumental in improving the rotary kiln. He was convinced that mass-produced portland cement could provide affordable housing for everyone, and in 1898, he formed the Edison Portland Cement Company in Orange, New Jersey. In 1902, his company introduced the long rotary kiln. At 150 ft long and nearly 9 ft in diameter, the kiln ensured more nearly complete calcining, which resulted in a better cement. By 1905, the company was producing 715 tons of cement per day (Conot, 1979). In 1908, Edison realized his dream of an all-concrete, low-cost housing project and was one of the first to use tilt-up wall construction—a method in which concrete walls are poured into a mold at the job site, allowed to harden, and then raised into place (Figure 11).

In a nearby magnetite mining operation managed by Edison and his associates, there was a problem of crushing the hard iron ore for processing. So, in his characteristic manner, Edison invented the modern roll crusher, which, like many of his other inventions, is universally used today in the cement and other mining industries. The crusher had two mammoth, rapidly rotating iron cylinders equipped with iron studs, and it could grind six tons of very hard magnetite boulders in half a minute. He fondly called it his "Giant Rolls" (Conot, 1979).

The construction of the 41-mi-long Panama Canal took 32 years; the canal was finally completed in 1914. An estimated 5 million yd<sup>3</sup> of concrete were used, and nearly 900 million yd<sup>3</sup> of earth were excavated (Legget and Karrow, 1983). Canal construction did much to foster the improvement of concrete standards and equipment in the United States. One example is the refinement of the ready-mix truck commonly seen on highways today.

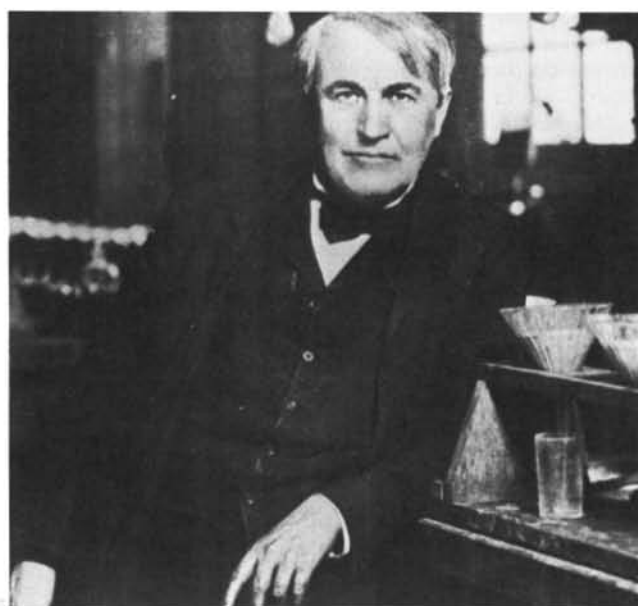


Figure 10. Thomas A. Edison, inventor. Edison pioneered the long rotary kiln and improved the crushing and grinding equipment used to make portland cement.

### Modern production

As important as portland cement is to society, it is reassuring to know that the resources used to make it are abundant and occur worldwide. The basic raw materials for making modern portland cement include about 60 percent lime (CaO), 25 percent silica (SiO<sub>2</sub>), 5 percent alumina (Al<sub>2</sub>O<sub>3</sub>), 4 percent gypsum (CaSO<sub>3</sub>·2H<sub>2</sub>O), 3 percent iron oxide (Fe<sub>2</sub>O<sub>3</sub>), and 3 percent



Figure 11. Tilt-up construction. The first tilt-up concrete buildings in the United States were used to store Army ammunition in the early 1900's. The thick, reinforced concrete walls are cast in place at the job site, allowed to harden, and tilted into place. Compared with other types, concrete tilt-up buildings take less time and money to construct and maintain. They require less insulation and cost less to heat in the winter and to cool in the summer compared with other types of buildings. They can be constructed quickly; some are completed 90 days from the time ground is broken. They eliminate the need of reinforcing beams and columns and require little long-term maintenance. Many innovative designs are used to make tilt-up buildings attractive. Photo by Don Dupras.



magnesium oxide (MgO). Lime comes from limestone and marl.<sup>5</sup> Silica and alumina are found in clays, shales, soils, and silica sand. Iron oxides occur in iron minerals, such as limonite, hematite, and siderite and in lateritic soils.

Magnesium oxide is a deleterious ingredient because in excessive amounts it expands over time and disintegrates concrete. However, all limestone contains small amounts of magnesium oxide, and it does not harm concrete if it is limited to amounts of less than 5 percent (Lea, 1970).

These raw cement materials are crushed, proportioned under exact chemical control, and ground to a sandy powder. The powder is then fed into a slightly inclined rotary kiln (some kilns are as long as 700 ft), and the load (or "charge") slowly moves toward the lower end, where it is first calcined and then gradually heated to a temperature of nearly 2,700 °F. This heating process normally takes approximately three to four hours. About 44 percent of the original load is lost as gases such as carbon dioxide and water vapor. When the charge reaches the "clinkering" temperature of 2,700 °F, it partially melts, changes composition, and emerges from the kiln as irregular, marble-sized balls called clinker<sup>6</sup> (Table 1) (Figure 12). The clinker is mixed with 2 to 4 percent gypsum to regulate setting time and is then ground to a powder finer than flour. The resulting gray powder is portland cement (Kosmatka and Panarese, 1988).

Over 99 percent of all concrete used today contains portland cement. An estimated 1,700 portland cement plants annually produce nearly a billion tons of cement worldwide (Huhta, 1988; Kosmatka and Panarese, 1988). California produces more portland cement, concrete aggregate, and portland cement concrete than any other state, and demand is expected to increase throughout the 1990's.

Table 1. Compounds in portland cement clinker\*

Chemical name	Formula	Industry abbrev.	Percent	Function in concrete
Tricalcium silicate	3 CaO·SiO <sub>2</sub>	C <sub>3</sub> S	55	Cementitious compound that adds strength, causes concrete to harden rapidly.
Dicalcium silicate	2CaO·SiO <sub>2</sub>	C <sub>2</sub> S	25	Cementitious compound that adds strength, causes concrete to harden slowly.
Tricalcium aluminate	3CaO·Al <sub>2</sub> O <sub>3</sub>	C <sub>3</sub> A	10	An essential flux that promotes fusing of hydrous crystals, liberates a large amount of heat during the first few days.
Tetracalcium aluminoferrite	4CaO·Al <sub>2</sub> O <sub>3</sub> ·Fe <sub>2</sub> O <sub>3</sub>	C <sub>4</sub> AF	8	Reduces heat of hydration, assists in the formation of cement crystal growth.

\* Clinker plus 4 percent ground gypsum (CaSO<sub>4</sub>·2H<sub>2</sub>O) constitutes portland cement; cement plus aggregate and water produces concrete.

<sup>5</sup> Marl is gray to dark gray. The term is loosely applied to rocks with 35 to 65 percent calcium carbonate and 35 to 65 percent clay. It is commonly called a "dirty limestone."

<sup>6</sup> Clinker and a small amount of gypsum are ground to a powder so fine that it will pass through a 200-mesh sieve with 40,000 openings per in<sup>2</sup> (about 10 microns in diameter). It is necessary to grind the cement this fine to increase the surface area so that it will properly hydrate.

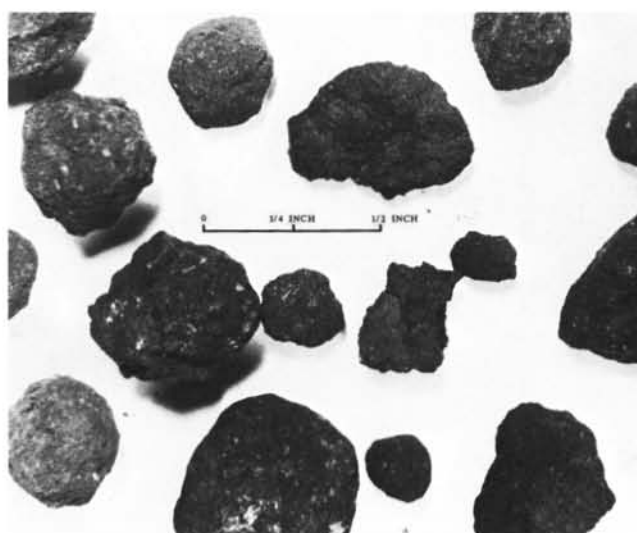


Figure 12. Grayish-black portland cement clinker pellets with an average diameter of 3/8 in. The raw materials for portland cement are heated to the clinkering temperature of approximately 2,700 °F. After the clinker is made in the rotary kiln, it is cooled, mixed with gypsum, and ground to the very fine powder known as portland cement. Photo by David Parke.

## PORTLAND CEMENT CONCRETE

Portland cement is rarely used by itself but must be mixed with aggregate to make concrete, grout, mortar, stucco, and the various other cement products used in the building industry. Portland cement mixed with fine aggregate (sand and gravel less than a quarter inch in diameter) is used to make cement plaster, mortar, and stucco. When it is mixed with sand and coarser aggregate (above a quarter of an inch in diameter), it makes concrete.

Nearly 99 percent of all structural concrete in the United States is made with portland cement. Portland cement is the most expensive component of concrete, and most types of concrete contain only about 7 to 14 percent cement by volume. When portland cement is mixed with the proper proportions of water (commonly 14 to 20 percent) and aggregate (commonly 60 to 80 percent by volume), the resulting concrete mix hardens—not by drying but by a process called hydration (Kosmatka and Panarese, 1988).

## Curing

At the instant water is added to the concrete matrix, anhydrous compounds in the cement chemically react and begin to form new compounds. During this hydration process, the new complex compounds firmly bind the concrete matrix with criss-crossed, interlocking hydrous crystals (Hansen, 1982). The rate of hydration is affected by the composition and fineness of the cement powder, temperature, the amount of water present, and admixtures that can either accelerate or retard the hydration process.

The hydration reaction is so rapid that it is necessary to lengthen the curing time by adding materials. Gypsum is almost universally added to cement to retard the setting, although many other additives are also available. For common concrete that is used in sidewalks, patios, and driveways, about 90 percent of the hydration process takes place within 28 days from the time it is poured. The hardening process, however, continues for months or years afterwards.

Long curing periods are desirable to yield more nearly complete hydration of concrete. Theoretical tests indicate that common concrete that is precisely engineered and cured will continue to strengthen for 25 years or longer (Kosmatka and Panarese, 1988).

Water must be available for the hydration process to continue. It is a common misconception that concrete hardens upon drying by evaporation. To avoid cracking and other problems, recently poured concrete projects should be kept moist for at least a week after they are placed. If poured concrete is not kept moist during the curing process, it can lose up to 50 percent of its designed strength. A common method of preventing the loss of moisture is to periodically spray the concrete with water or cover it with wet rugs or burlap bags. Another method used in large construction projects is to spray membrane-curing compounds on the fresh concrete; the membrane acts as a barrier to evaporation.

To make sound concrete, only that amount of water necessary for hydration is required. However, a concrete mix that contains only the amount of water necessary for hydration is stiff (or "lean," as it is known in the trade) and is laborious to place. Because such a lean concrete is difficult to place and work, more water is commonly added to make the mix easier to pour and finish. The addition of more water than is required for hydration lowers the strength of the concrete (Waddell, 1974, 1985).

For example, an average machine-mixed concrete blend can withstand pressures of 3,000 lb per in<sup>2</sup> 28 days after it is placed. If extra water is added to the mix to make it easier to place and finish, the concrete strength may be only 1,500 lb per in<sup>2</sup> after 28 days. If the concrete is used to make a front yard mowing strip, the reduction in strength is not important. If, however, the concrete is used for a building foundation, the strength reduction may be serious. If too much water is added to the mix, there is not only a significant loss of strength but also the risk that the pieces of aggregate may separate from the matrix and the concrete will fail.

Heat is generated during the hydration process, and when large amounts of concrete are poured, as in dams or bridge abutments, the heat from the hydration is reduced or drawn off to avoid damaging the concrete. For large construction jobs (dams, bridge foundations, or freeway overpasses), specialty cements that produce less heat and take longer to cure are used (Kosmatka and Panarese, 1988).

### Placing

Portland cement concrete for dams and large bridges is mixed near the construction site. For smaller jobs, it is brought to the construction site ready-mixed in agitator trucks. Ready-mix trucks, with their characteristic tilted, rotating, barrel-shaped mixers, deliver the concrete in readiness from a central plant called a "batch plant." The truck operator then places the fresh concrete by means of a metal chute that folds out from the back of the truck. It is important to place concrete from the mixer to the form as rapidly as possible so that no initial setting occurs. The entire ready-mix operation from batch plant to placement is usually completed within 90 minutes.

When placing fresh concrete in difficult-to-reach areas, such as when constructing skyscrapers, concrete is pumped through a long tremie hose attached to a crane. Some concrete pump trucks can lift and place concrete above 500 vertical ft. For large jobs or when structural support is critical, the concrete is agitated after it is poured by portable vibrators to ensure that no void spaces remain in the corners and recesses of the form.

### Reinforced concrete

Although sound concrete can withstand intense vertical pressure called "compressive strength," its resistance to tensile stress (or pull-apart force) is relatively weak. In other words, a standing pillar of concrete that is 4 in. wide and 6 ft tall would be easy to break with a sideways hammer blow. To remedy this imperfection, engineers use reinforcing materials that have high tensile strength. The most common type of material used is steel rebar (rods). In addition to its high tensile strength, concrete reinforced with steel rebar will expand in the summer and contract in the winter at an even rate, with no damage to the concrete. Steel rebar is ribbed to improve

its bond with concrete (Figure 13). In general, the thicker the reinforced concrete structure, the thicker the rebar used. Welded, high-strength wire meshes are used in the construction of road, floor, and flat-roof concrete slabs.

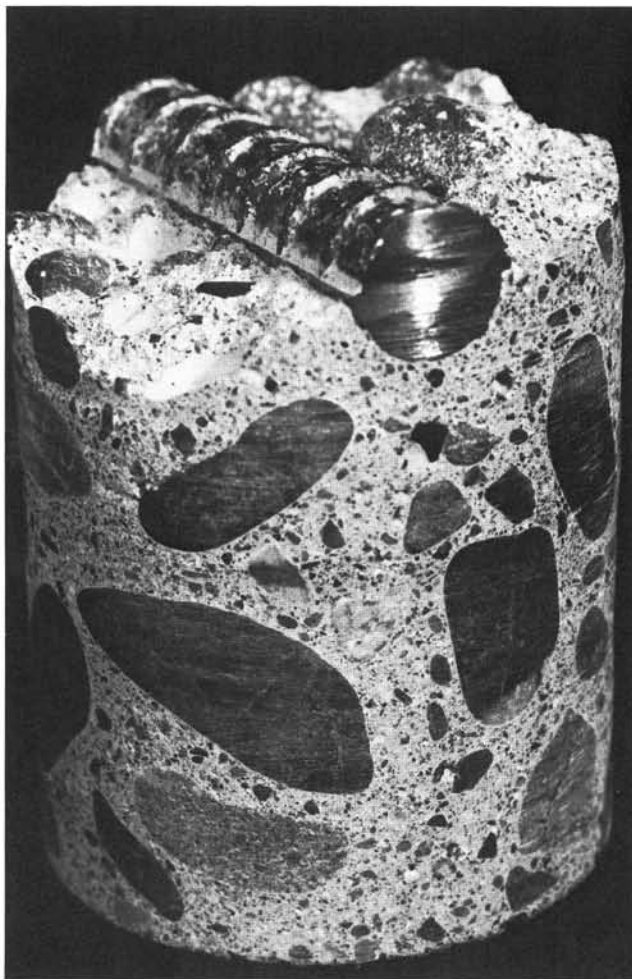


Figure 13. Columnar section of rebar concrete taken from a building foundation. Samples such as this are extracted from building foundations and tested to ensure that the rebar and concrete are sound. Note how the cement-and-water paste completely coats each aggregate particle. Photo by David Parke.

### Concrete failure

Concrete failures are usually caused by faulty construction techniques rather than by flawed design. When a large concrete structure fails, engineers use a variety of forensic tools to determine what happened. High-frequency sound waves, for example, are commonly used to determine the structural strength of concrete. Because the speed of sound in concrete is known, the time it takes the sound wave to pass through concrete can be translated into feet and inches. Similarly, sound waves sent through concrete foundation footings, walls, or columns can be monitored for unusual patterns of deflection that indicate the presence of interior cracks, air pockets, or extraneous items. In one failed concrete structure, a lunch pail was found to have been inadvertently left behind when the concrete was poured (Allman, 1988).

To ensure that reinforcing steel rebar has been properly placed in concrete structures, portable X-ray machines and instruments that measure fluctuations in a magnetic field are used (Allman, 1988).

A common problem that is especially prevalent in marine structures is rebar corrosion hidden within the concrete. Engineers use portable instruments to measure the rebar corrosion by measuring the electric potential on the surface of the concrete. Sharp surges and variations of electric potential that differ from calibrated electric amounts of undamaged concrete indicate the amount of concealed corrosion.

## CONCLUSION

Concrete is the most common building material in the world. It is a marvel of civilization that has been used for thousands of years and will remain a necessary building material for a long time to come. In the days of ancient Rome, the development of concrete was made by trial and error. In contrast, researchers today are aggressively using the scientific method to fully understand the myriad complex chemical reactions that take place to create lighter, stronger, and more durable concrete structures. The introduction of innovative types of concrete is changing the way architects and engineers design and build bridges and the many other concrete structures we rely upon and take for granted.

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## NEW PUBLICATIONS RECEIVED IN LIBRARY

*From time to time, we announce the receipt of new publications from outside sources that we think will be of interest to our readers. Copies of these publications are currently in the library of the Oregon Department of Geology and Mineral Industries, where they may be examined. Information about ordering and prices are listed below.*

**The Art of Geology**, edited by Eldridge M. Moores, Department of Geology, University of California at Davis, and F. Michael Wahl, Geological Society of America. Published in 1988 as Special Paper 225 by the Geological Society of America, 3300 Penrose Place, P.O. Box 9141, Boulder, Colorado 80301. Hardbound, 9-in. by 12-in. format, 147 pages, full color throughout, with dust jacket, price \$37.50 postpaid.

Designed to celebrate the 1988 Centennial of the Geological Society of America (GSA) and inspired by geologic photos submitted for the cover of GSA's monthly journal *Geology*, this handsome volume contains 250 scenic and geologic photographs arranged in 69 essays, each accompanied by a brief nontechnical text. Following a colorful rendition of the geologic time scale and an introduction discussing briefly the history of GSA, geologic time, geologic processes, and plate tectonics, the book opens with a startlingly beautiful series of photographs of slot canyons of the Colorado Plateau. Places such as Svartifoss Waterfall in Iceland, Tambora Volcano in Indonesia, Teton National Park in Wyoming, Cordillera del Paine in Chile, the Brooks Range in Alaska, Rodadero in Peru, Arches National Park in Utah, Suez Rift in Egypt, and Central Park in New York City are subjects of photographic essays. The scale of pictures ranges from photomicrographs of peridotite from a South African diamond pipe to radar imagery of folds on the planet Venus. Geologic features such as thrust faults in Spain, unconformities in the Grand Canyon, ground-water erosion in Utah, and karst towers in China produce striking photographs.

All in all, this fascinating book is an appropriate way for GSA to celebrate its first 100 years—by sharing the visual wonders of geology with those of us who have not yet had the opportunity of seeing them first hand.

**Northwest Correlation Chart, Correlation of Stratigraphic Units in North America (COSUNA) Project**, chart coordinators, Donald A. Hull, John M. Armentrout, Lehi F. Hintze, John D. Beaulieu, and Weldon W. Rau; chart editor, F. Alan Lindberg; with contributions by W.O. Addicott, J.M. Armentrout, E.M. Baldwin, J.D. Beaulieu, M.H. Beeson, M.E. Brownfield, W.G. Bruer, R.J. Deacon, D.J. Easterbrook, V.A. Frizzell, L. Hintze, D.A. Hull, S.Y. Johnson, K.B. Kelty, D.L. Lander, V.S. Mallory, K.A. McDougall, D.R. McKeel, G.A. Miles, A.R. Niem, W.N. Orr, W.W. Rau, P.D. Snively, Jr., R.O. VanAtta, and R.E. Wells. Published in 1988 as part of its Chart Series by the American Association of Petroleum Geologists, P.O. Box 979, 1444 South Boulder, Tulsa, Oklahoma 74101. Multicolored chart 55 in. by 41 in., price \$8 plus \$1.75 shipping charges.

This is the last of the 20 correlation charts of the United States published as part of the COSUNA project by the American Association of Petroleum Geologists (AAPG) Research Committee in cooperation with the Committee on Stratigraphic Correlations. The charts are intended to show stratigraphic columns that provide fairly complete coverage of the geology of the United States. The Northwest Correlation Chart contains sections for Oregon, Washington, and Idaho, including the Roseburg area, Cape Blanco area, Coos Bay area, Reedsport (subsurface), Eugene area, central Coast Range, McMinnville-Sheridan area, Oregon City-Molalla area, Astoria area, Columbia County area, south flank of the Willapa Hills, Grays Harbor Basin, Centralia-Chehalis area, western Olympic Peninsula, northwest Olympic Peninsula, northeast Olympic Peninsula, Bremer-

*(Continued on page 46, New Publications)*

## DOGAMI releases first reports of 1989

### State Map Advisory Council publishes annual report for 1988

The State Map Advisory Council for Oregon (SMAC) has released its annual report, a summary of its activities and accomplishments in 1988. The Council was established by Governor Neil Goldschmidt by Executive Order in 1987.

The 122-page report, which was produced under the chairmanship of State Deputy Geologist John D. Beaulieu and published by the Oregon Department of Geology and Mineral Industries (DOGAMI) as Open-File Report O-89-1, sells for \$5.

The report provides summaries of over 20 meetings of the Council in its Executive Board, the Oregon Map Advisory Committee, the Oregon Geographic Information Systems Committee, and the Oregon Land Records Committee. Appendices describe the nature, mission, and goals of the State Map Advisory Council and its committees and present selected major plans, proposals, and budget priorities for 1989. The report concludes with membership lists of the various committees.

The Oregon SMAC is the lead governmental body in Oregon for mapping discussions. It consists of representatives from Federal and State agencies, local government, and private industry. Its purpose is to focus computerized mapmaking activities in Oregon and to further most efficient coordination of efforts.

### Map for Mist Gas Field updated

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released an updated version of the Mist Gas Field map. The new map reflects all 1988 drilling activity in the field, including gas-storage and monitor-well activity. It has been published as DOGAMI Open-File Report O-89-2 and sells for \$5.

The Mist Gas Field Map defines a 141-mi<sup>2</sup> area within which special setback distances for gas wells are applied. The map is at a scale of 1:24,000 and measures approximately 40x50 in. It shows the Mist Gas Field divided into quarter sections and the setback lines for each section. Also shown on the map are the locations of all wells drilled, their total depth and year of completion, and all drilling locations permitted through 1988.

The official boundaries of the Mist Gas Field were approved by the DOGAMI Board of Governors in 1983, after a public hearing in which the previously accepted, unofficial field boundaries were revised.

### New geologic quadrangle map for Owyhee region released

Geology and Mineral Resources Map of the Graveyard Point Quadrangle, Malheur County, Oregon, and Owyhee County, Idaho, by DOGAMI geologist Mark L. Ferns, has been released in DOGAMI's Geological Map Series as map GMS-54 and sells for \$4. The publication, resulting from an ongoing study of southeastern Oregon areas with a potential for mineral resources, was prepared in cooperation with the U.S. Geological Survey (USGS) and the Idaho Geological Survey and was partially funded by the COGEOMAP program of the USGS.

The Graveyard Point 7½-minute quadrangle covers approximately 48 mi<sup>2</sup> east of Lake Owyhee and Owyhee Ridge and extends a little over a mile across the state line into Idaho. The new two-color map of the quadrangle (scale 1:24,000) identifies 19 Tertiary and Quaternary rock units, the oldest of which may date back to the late Oligocene (25 million years before the present). Geologic structure is described both on the map and in an accompanying cross section.

The approximately 28- by 40-in. map sheet also includes a discussion of the area's mineral-resource potential and tables showing whole-rock and trace-element analyses of rock samples. A variety of valuable and potentially valuable mineral resources were found or indicated by the study, including bentonite clay, clinoptilolite zeolite, gold, mercury, semiprecious gemstones, building stone, and geothermal resources. □

## Earthquake hazard workshop to be held in Portland

The 1989 Workshop on Earthquake Hazards in the Puget Sound/Portland Area will be held March 28, 29, and 30, 1989, at the Portland Marriott Hotel in Portland, Oregon.

Sponsored by the Oregon Department of Geology and Mineral Industries (DOGAMI), the Oregon Department of Emergency Management, the Washington Department of Natural Resources, the Washington Department of Community Development, the Federal Emergency Management Agency, and the U.S. Geological Survey, the workshop has been designed to facilitate transfer of technical information from the geoscience community to engineers, planners, emergency responders, government officials, and members of the business community.

To improve the transfer of information, the first day of the workshop will have two parallel sessions: (1) a technical session in which geoscientists will present and discuss short papers, and (2) a nontechnical tutorial session in which basic technical issues will be explained and case histories illustrating major principles will be presented. The technical session will address topics such as faulting and seismicity of northwestern Oregon, southwestern Washington, and British Columbia; megathrust paleoseismicity; Cascadia margin deformation and megathrust ground motions; coastal terraces and subduction earthquakes; crustal and intraplate earthquake ground motions; liquefaction hazards; and tsunami modeling. The nontechnical session will cover such topics as Pacific Northwest plate tectonics and earthquake sources, basic seismology, special features of subduction zone earthquakes, ground response and failure, and building response and design. The first day will conclude with an evening poster session.

The second day of the workshop will provide brief technical summaries of the state of knowledge about earthquake hazards in the Portland and Puget Sound regions and an afternoon session on mitigation and policy, addressing such topics as existing earthquake hazard policies, response to changing earthquake hazards at the Trojan nuclear power plant, the Pacific Northwest view of earthquake hazards, and the Armenian earthquake of 1988.

The third day of the workshop will be a field trip to Netarts Bay, Oregon, to view evidence for Holocene and Pleistocene subsidence events presumably associated with large earthquakes. The trip will be led by Mark Darienzo, one of the authors of the *Oregon Geology* 1988 field trip guide to the same area ("Coastal Neotectonic Field Trip Guide for Netarts Bay, Oregon," by C.D. Peterson, M.E. Darienzo, and M. Parker, *Oregon Geology*, v. 50, no. 9/10, p. 99-106).

Cost of registration for the workshop, which includes the first two days of the workshop and a luncheon on the second day, has been tentatively set at \$35. The field trip will cost \$15, which will cover transportation to Netarts Bay, lunch, and a field trip guide. For additional information, in Oregon, contact Ian Madin, phone (503) 229-5580. In Washington, contact Ray Lasmanis, phone (206) 459-6372, or Linda Nosen, phone (206) 481-4694. □

## To our readers

*Oregon Geology* changed from monthly to bimonthly publication after last year's April issue, and eight issues were published in 1988. We marked the change by giving the last four issues double numbers and putting the names of two months on each issue.

This year, however, we are publishing a total of six issues, published in January, March, May, July, September, and November. These issues will all carry plain numbers, from one to six.

We value our subscribers, and we thank you for your continued support of *Oregon Geology*. Please do not hesitate to let us know of your wishes, comments, and news, so that we may serve you even better in the future. □



## DOGAMI installs display at Capitol

Staff members of the Oregon Department of Geology and Mineral Industries (DOGAMI) installed a new display on the main floor of the State Capitol in January 1989. Housed in the display case of the Oregon Council of Rock and Mineral Clubs near the gift shop, the display is built around the theme "Oregon's Hidden Wealth: Minerals."



DOGAMI display with theme "Oregon's Hidden Wealth: Minerals" will be at State Capitol until mid-May.

In the display, a minerals map of the State of Oregon has been divided into five sections—northeast, southeast, central, northwest, and southwest—and information about the mineral resources in each section is presented by photographs, maps, and actual samples. Included are samples of placer gold, sunstones, thunderegg, limestone, gold ore, soapstone sculpture, pumice, obsidian, the Clark and Wilson sandstone, and numerous cut and polished semiprecious stones. Featured are samples of rock brought up from a depth of more than 10,000 ft from the Gorda Ridge off the coast of Oregon and black sand samples from the Oregon coast, including garnet, ilmenite, chromite, and platinum concentrates. Also included is a sample of black sand concentrate containing numerous flakes of gold.



DOGAMI staff members Paul Staub and Mark Neuhaus installing display at State Capitol.

The importance of less glamorous but economically important materials is stressed by photos of and information about sand and gravel, brick, diatomite, zeolite, and bentonite operations in the state. Photographs of examples of the State's extremely successful Mined Land Reclamation Program are included.

The display, which will remain in place until mid-May, is designed to inform Oregonians about the importance of their mineral resources. □

## Faceters to meet in May

The 14th Annual Northwest Faceters Conference will be held starting Friday evening, May 26, and continuing on through the weekend of May 27 and 28, 1989, at the Lloyd Center Red Lion Inn in Portland. Sponsored by the Columbia-Willamette Faceters Guild, the meeting is designed to provide a forum where faceters and gemcutters can learn more about obtaining material and cutting it to best advantage. Included on the program will be presentations by Ron Geitgey, Oregon Department of Geology and Mineral Industries, on sunstones and other gemstones of Oregon; and by Ron Aggee, the man who cut the world's largest topaz. A competition to decide who cut the best single stone will be held, and awards will be given at the Saturday noon banquet. Dealers will also be present at the conference, with equipment, uncut gemstone material, and jewelry findings.

Registration price for the conference, which will be \$35, includes cost of the banquet. For additional information, contact Grover Sparkman, 3327 SE 50th Avenue, Portland, Oregon 97206, day phone (503) 775-6725, and evening phone, (503) 774-0048. □

### (New Publications, continued from page 44)

ton area, Seattle area, Carbon River area, Pasco-Yakima-Ellensburg area, Columbia River-The Dalles area, Bend-Madras-Ochoco Mountains, Lakeview-Fort Rock-Klamath Falls, John Day-Suplee, Harney Basin to Steens Mountain, Pullman to Snake River Gorge, Baker County and Wallowa Mountains, Juntura-Vale-Owyhee Dam, and Boise Basin. The Oregon Department of Geology and Mineral Industries (DOGAMI) published a preliminary form of this chart along with data sheets in 1983 as Oil and Gas Investigation 7, *Correlation of Cenozoic Stratigraphic Units of Western Oregon*, which may be purchased from DOGAMI for \$8.

The complete set of 20 COSUNA charts may be purchased from AAPG for \$99. Prices for individual charts range from \$8 to \$12, and AAPG should be contacted for prices of specific charts. Detailed information regarding contacts, lithology, paleontology, references, and other data for each of the units on any of the charts is available by accessing the computerized data base through the University of Oklahoma, Norman, Oklahoma.

**Fire Mountains of the West: The Cascade and Mono Lake Volcanoes**, by Stephen L. Harris, Sacramento State University. Published in 1988 by Mountain Press Publishing Company, P.O. Box 2399, Missoula, Montana 59806. Paperback; 6-in. by 9-in. format; 389 pages; 148 illustrations including photographs, two-color maps, cross-sections, and schematic diagrams; price \$15.95; available at local bookstores.

*Fire Mountains of the West* is a complete revision of Harris' popular book *Fire and Ice*. Designed for the nontechnical reader, *Fire Mountains of the West* describes the major Cascade volcanoes and those in California's Mono-Mammoth Lake area, describing locations; geography; history—both human and geologic; hazards; and ways to approach and explore each particular area. The theory of plate tectonics, categories of volcanoes, types of magmas, evolution of the Cascades, and glaciation are topics that are presented in simple terms with numerous easy-to-understand illustrations and appropriate photographs.

Although not designed to be used as a field-trip guide, this book provides rich details that will enhance anyone's appreciation of a specific volcano, even though he or she has visited it before. Because the book is nontechnical in style, Harris has not had to encumber his prose with the numerous citations that most technical papers require, making *Fire Mountains of the West* much easier to read and enjoy. He is careful, however, to cite and thank the people whose work have made this book possible, and he includes a bibliography for each chapter. Also included are a glossary and index.

For people who want to learn more about the Cascade volcanoes—their origins, histories, and futures—this book is highly recommended. □

## AVAILABLE DEPARTMENT PUBLICATIONS

### GEOLOGICAL MAP SERIES

	Price	No. copies	Amount
GMS-4. Oregon gravity maps, onshore and offshore. 1967	\$ 3.00		
GMS-5. Geologic map, Powers 15-minute quadrangle, Coos and Curry Counties. 1971	3.00		
GMS-6. Preliminary report on geology of part of Snake River canyon. 1974	6.50		
GMS-8. Complete Bouguer gravity anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-9. Total-field aeromagnetic anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-10. Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	3.00		
GMS-12. Geologic map of the Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	3.00		
GMS-13. Geologic map, Huntington and part of Olds Ferry 15-min. quadrangles, Baker and Malheur Counties. 1979	3.00		
GMS-14. Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00		
GMS-15. Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	3.00		
GMS-16. Free-air gravity anomaly map and complete Bouguer gravity anomaly map, south Cascades, Oregon. 1981	3.00		
GMS-17. Total-field aeromagnetic anomaly map, south Cascades, Oregon. 1981	3.00		
GMS-18. Geology of Rickreall, Salem West, Monmouth, and Sidney 7½-min. quads., Marion/Polk Counties. 1981	5.00		
GMS-19. Geology and gold deposits map, Bourne 7½-minute quadrangle, Baker County. 1982	5.00		
GMS-20. Map showing geology and geothermal resources, southern half, Burns 15-min. quad., Harney County. 1982	5.00		
GMS-21. Geology and geothermal resources map, Vale East 7½-minute quadrangle, Malheur County. 1982	5.00		
GMS-22. Geology and mineral resources map, Mount Ireland 7½-minute quadrangle, Baker/Grant Counties. 1982	5.00		
GMS-23. Geologic map, Sheridan 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-24. Geologic map, Grand Ronde 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-25. Geology and gold deposits map, Granite 7½-minute quadrangle, Grant County. 1982	5.00		
GMS-26. Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00		
GMS-27. Geologic and neotectonic evaluation of north-central Oregon. The Dalles 1°x2° quadrangle. 1982	6.00		
GMS-28. Geology and gold deposits map, Greenhorn 7½-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-29. Geology and gold deposits map, NE¼ Bates 15-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-30. Geologic map, SE¼ Pearssoll Peak 15-minute quadrangle, Curry/Josephine Counties. 1984	6.00		
GMS-31. Geology and gold deposits map, NW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-32. Geologic map, Wilhoit 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-33. Geologic map, Scotts Mills 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-34. Geologic map, Stayton NE 7½-minute quadrangle, Marion County. 1984	4.00		
GMS-35. Geology and gold deposits map, SW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-36. Mineral resources map of Oregon. 1984	8.00		
GMS-37. Mineral resources map, offshore Oregon. 1985	6.00		
GMS-38. Geologic map, NW¼ Cave Junction 15-minute quadrangle, Josephine County. 1986	6.00		
GMS-39. Geologic bibliography and index maps, ocean floor and continental margin off Oregon. 1986	5.00		
GMS-40. Total-field aeromagnetic anomaly maps, Cascade Mountain Range, northern Oregon. 1985	4.00		
GMS-41. Geology and mineral resources map, Elkhorn Peak 7½-minute quadrangle, Baker County. 1987	6.00		
GMS-42. Geologic map, ocean floor off Oregon and adjacent continental margin. 1986	8.00		
GMS-43. Geologic map, Eagle Butte and Gateway 7½-min. quads., Jefferson/Wasco Co. 1987	\$4.00; as set with GMS-44 & -45. 10.00		
GMS-44. Geologic map, Seekseequa Junction/Metolius Bench 7½-min. quads., Jefferson Co. 1987	\$4.00; as set with GMS-43 & -45. 10.00		
GMS-45. Geologic map, Madras West and Madras East 7½-min. quads., Jefferson County. 1987	\$4.00; as set with GMS-43 & -44. 10.00		
GMS-46. Geologic map, Breitenbush River area, Linn/Marion Counties. 1987	6.00		
GMS-47. Geologic map, Crescent Mountain area, Linn County. 1987	6.00		
GMS-48. Geologic map, McKenzie Bridge 15-minute quadrangle, Lane County. 1988	8.00		
GMS-49. Map of Oregon seismicity, 1841-1986. 1987	3.00		
GMS-50. Geologic map, Drake Crossing 7½-minute quadrangle, Marion County. 1986	4.00		
GMS-51. Geologic map, Elk Prairie 7½-minute quadrangle, Marion/Clackamas Counties. 1986	4.00		
GMS-53. Geology and mineral resources map, Owyhee Ridge 7½-minute quadrangle, Malheur County. 1988	4.00		
<b>NEW!</b> GMS-54. Geology and mineral resources map, Graveyard Point 7½-minute quad. Malheur/Owyhee Counties, Oregon/Idaho. 1988	4.00		

### BULLETINS

33. Bibliography of geology and mineral resources of Oregon (1st supplement, 1937-45). 1947	3.00		
35. Geology of the Dallas and Valsetz 15-minute quadrangles, Polk County (map only). Revised 1964	3.00		
36. Papers on Foraminifera from the Tertiary (v.2 [parts VI-VIII] only). 1949	3.00		
44. Bibliography of geology and mineral resources of Oregon (2nd supplement, 1946-50). 1953	3.00		
46. Ferruginous bauxite deposits, Salem Hills, Marion County. 1956	3.00		
53. Bibliography of geology and mineral resources of Oregon (3rd supplement, 1951-55). 1962	3.00		
61. Gold and silver in Oregon. 1968	17.50		
65. Proceedings of the Andesite Conference. 1969	10.00		
67. Bibliography of geology and mineral resources of Oregon (4th supplement, 1956-60). 1970	3.00		
71. Geology of selected lava tubes, Bend area, Deschutes County. 1971	5.00		
78. Bibliography of geology and mineral resources of Oregon (5th supplement, 1961-70). 1973	3.00		
81. Environmental geology of Lincoln County. 1973	9.00		
82. Geologic hazards of Bull Run Watershed, Multnomah and Clackamas Counties. 1974	6.50		
85. Environmental geology of coastal Lane County. 1974	9.00		
87. Environmental geology of western Coos and Douglas Counties. 1975	9.00		
88. Geology and mineral resources, upper Chetco River drainage, Curry and Josephine Counties. 1975	4.00		
89. Geology and mineral resources of Deschutes County. 1976	6.50		
90. Land use geology of western Curry County. 1976	9.00		
91. Geologic hazards of parts of northern Hood River, Wasco, and Sherman Counties. 1977	8.00		
92. Fossils in Oregon. A collection of reprints from the <i>Ore Bin</i> . 1977	4.00		
93. Geology, mineral resources, and rock material of Curry County. 1977	7.00		
94. Land use geology of central Jackson County. 1977	9.00		
95. North American ophiolites (IGCP project). 1977	7.00		
96. Magma genesis. AGU Chapman Conference on Partial Melting. 1977	12.50		
97. Bibliography of geology and mineral resources of Oregon (6th supplement, 1971-75). 1978	3.00		
98. Geologic hazards of eastern Benton County. 1979	9.00		
99. Geologic hazards of northwestern Clackamas County. 1979	10.00		
100. Geology and mineral resources of Josephine County. 1979	9.00		
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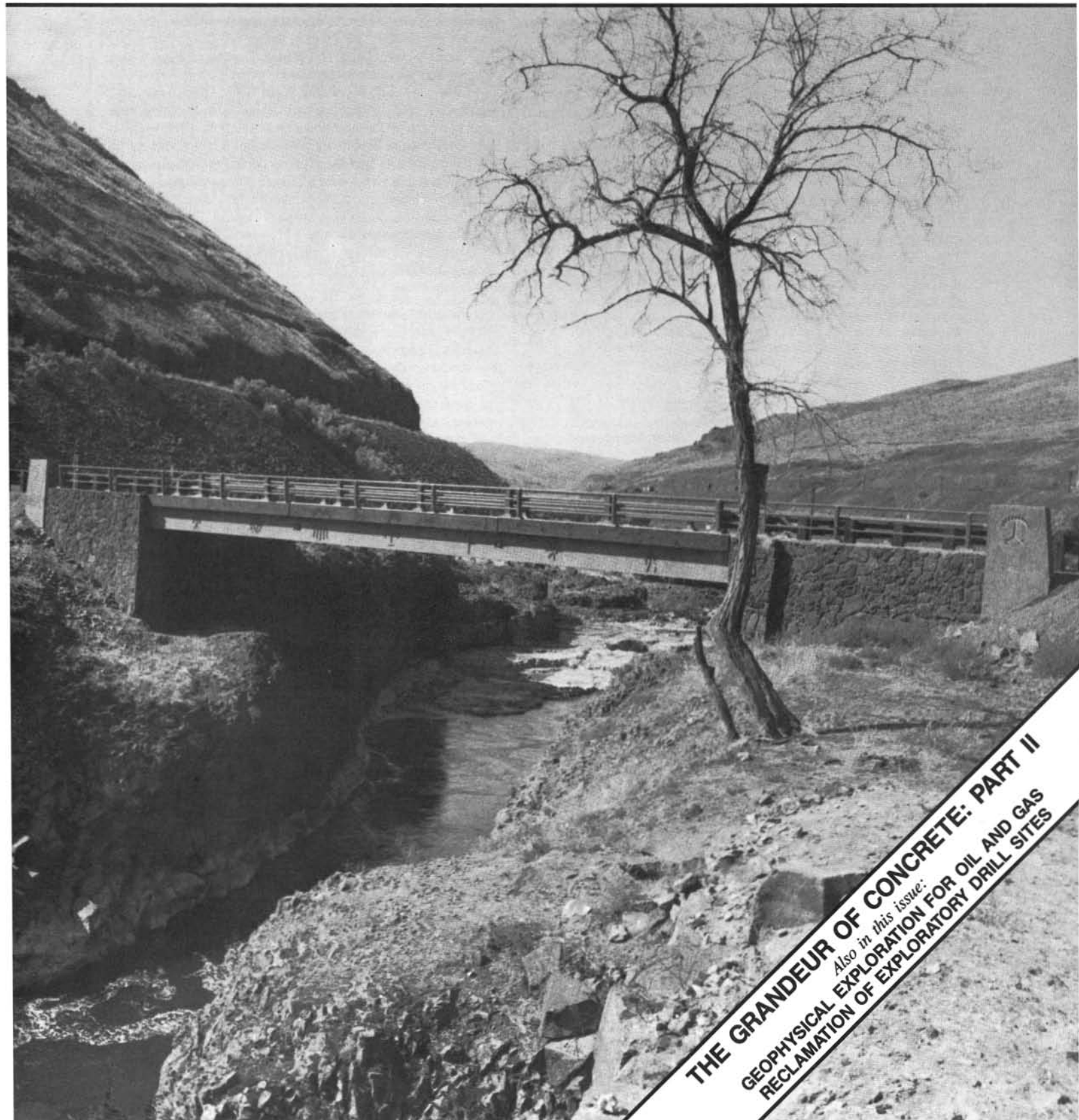
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**THE GRANDEUR OF CONCRETE: PART II**  
*Also in this issue:*  
**GEOPHYSICAL EXPLORATION FOR OIL AND GAS**  
**RECLAMATION OF EXPLORATORY DRILL SITES**



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## COVER PHOTO

Sherars Bridge in Wasco County, Oregon, near Tygh Valley and Maupin, where State Highway 216 crosses the fast-flowing Deschutes River. At this point, the river has cut a channel 80 ft deep and barely 40 ft wide into volcanic rock, offering a crossing point for an ancient Indian trail. Peter Skene Ogden arrived here in 1826 and reported finding a footbridge. From 1860 on, a bridge was maintained here for pioneer wagon trains.

The relatively simple prestressed-concrete slab construction received special architectural treatment because of the historic and scenic significance of the locality. It is the site of traditional Indian fishing camps and part of the Deschutes River Scenic Waterway. Designs based on Indian pictographs carved on a nearby cliff were formed into the sides of the exterior deck slabs and the pedestrian rail posts. The acceptability of the designs was cleared with the Council of the Confederated Tribes of the Warm Springs. The concrete abutments and wing walls were faced with native stone, and the metal bridge rail was painted a bronze color, so that the structure would blend in with its surroundings. Photo courtesy of OCAPA.

## Position Announcements

Oregon Department of Geology and Mineral Industries

### Geologist IV — Senior Geologist

Full-time, senior-level, permanent position, available August 1, 1989. Starting salary approximately \$2,600-2,900 per month plus benefits. Location is Grants Pass, Oregon.

Graduate degree or equivalent is required, as well as a minimum of five years of progressively responsible experience in conducting and managing field projects, preferably including economic geology and geologic mapping in volcanic, Tertiary marine sedimentary West Coast, and/or pre-Tertiary terranes. Provinces include Basin and Range, Cascade Range, Coast Range, and Klamath Mountains.

Duties include supervising small field office; designing, supervising, and coordinating multi-year economic-geology and geologic-map projects; conducting active field work; writing clear and concise reports for publication; active reviewing of geologic aspects of land use planning documents and processes; and dealing effectively with a diverse public. Emphasis is on geologic mapping and geologic reports for publication. Position requires close coordination with Federal, State, university, and industry counterparts.

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Duties include designing, conducting, and coordinating economic-geology and geologic-map projects; conducting active field work; writing clear and concise reports for publication; participating in the geologic aspects of land use planning; and dealing effectively with a diverse public. Emphasis is on geologic mapping and geologic reports for publication. Position requires close coordination with Federal, State, university, and industry counterparts.

Deadline for receipt of the completed application packet is August 1, 1989.

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# The grandeur of concrete: Part II

by Don Dupras, Geologist, California Division of Mines and Geology

This article is the second of a two-part series describing how concrete is made and how important it is in our lives. The series first appeared in the January and February 1989 issues of *California Geology* and is reprinted here by permission because we believe it will be of interest to our readers. Part II presents principles of concrete making and current developments in concrete technology that enable architects and engineers to design and construct superior structures. Part I was reprinted in the March issue of *Oregon Geology*. Photos are by Don Dupras except as noted. —Editor

## DEPENDENCE ON CONCRETE

Concrete is the least expensive, most plentiful, and most commonly used building material on earth. Annual world consumption of concrete is nearly one ton for every person on the planet. The raw materials for making concrete—cement, aggregate, and water—are abundant and are found in nearly every country. Concrete technology can either be adapted to labor-intensive methods frequently used in developing countries or to highly mechanized processes common in the United States and other industrialized countries (Weisburd, 1988).

Nearly all modern buildings stand on concrete foundations, and many are constructed with concrete frames, floors, walls, and roofs. Water is carried through concrete pipes, cars and trucks use concrete highways, planes land on concrete runways, and ships berth at concrete docks. It is hard to imagine our society without the benefit of concrete.

Concrete consumption increases as the population grows, and there is a corresponding demand for housing, manufactured goods, and related services. World concrete manufacture has risen steeply in the past decade; the rate of concrete consumption is expected to increase as developing nations continue to expand their infrastructures. Massive concrete projects, such as hydroelectric dams, airports, and aqueducts, are being constructed throughout the world, and many more are planned.

Annual use of concrete in the United States amounts to twice the total of all other construction materials combined—such as wood, structural steel, brick, tile, aluminum, and building glass. At a cost of about two cents a pound, the value of all concrete-based structures in the United States is estimated to be \$6 trillion (Weisburd, 1988).



Bonneville Lock and Dam on the Columbia River, approximately 30 mi east of Portland, Oregon, connecting the Oregon and Washington sides of the river over a distance of about three-quarters of a mile. Built originally between 1933 and 1937 and enlarged in the early 1970's, the dam now combines the oldest and newest federal power plants on the Columbia. Lake Bonneville, the 48-mi-long reservoir impounded by the dam, is the first in a series of navigable lakes that are part of a water highway running 470 mi from the Pacific Ocean to Lewiston, Idaho. The Bonneville Lock and Dam project was placed on the National Register of Historic Places in 1986 and has been designated as a National Historic Landmark. Enormous quantities of concrete were used in this mass-concrete construction. Photo courtesy of U.S. Army Corps of Engineers, Portland District.

In addition to producing more portland cement than any other state, California also produces more concrete aggregate than any other state. In 1987, California produced an estimated 135.7 million tons of construction aggregate worth about \$536 million (Burnett, 1988).<sup>1</sup> Of the ten largest aggregate producers in the United States, eight are in California (Table 1) (Rukavina, 1988). Much of the aggregate is used in concrete.

Table 1. Ten largest aggregate plants in the United States (from Rukavina, 1988)

Rank	Company (plant name)	County, state	1987 production in millions of tons
1	Koppers/Sully-Miller Company (Irwindale 67)	Los Angeles, CA	4.62
2	CalMat Company (Sun Valley)	Los Angeles, CA	4.60
3	Koppers/Kaiser Sand and Gravel Company (Radium)	Los Angeles, CA	3.90
4	A. Teichert and Son Sand and Gravel (Perkins)	Sacramento, CA	—*
5	Lone Star/Northwest Aggregates Company (Steilacoom)	Pierce, WA	3.51
6	Transit Mix Concrete Company (Azusa)	Los Angeles, CA	3.50
7	Livingston-Graham Company (Irwindale)	Los Angeles, CA	3.46
8	Owl Rock (Azusa Spreading Grounds)	Los Angeles, CA	3.20
9	Salt River Sand and Rock (Dobson)	Maricopa, AZ	—*
10	Jamieson Company (Pleasanton Pit)	Alameda, CA	2.30

\* Production figures are proprietary.

## CONCRETE INTEGRITY

When made in the appropriate way, concrete is durable and permanent. Some concrete structures have retained their integrity for over a century. However, if improper methods or inferior ingredients are used, concrete can be easily rendered worthless. Even after it is poured, concrete can be damaged by attack from acids and sulfates. Sulfates, such as sodium sulfate ( $\text{Na}_2\text{SO}_4$ ), are especially harmful because they form sulfuric acid, which attacks the lime compounds in concrete. Contact with these deleterious compounds has to be avoided when using normal concrete.

For some construction jobs, engineers use special cements and techniques to design concrete structures that are better able to resist attack from injurious chemicals. For example, in areas where concrete will be exposed to severe sulfate attack, such as from sulfate soils or ground water, sulfate-resistant cement concrete is used.



Spillway of Bonneville Dam (photo above). The term "mass concrete" used for this kind of construction refers to the fact that the concrete in these structures often is several feet thick. Photo courtesy of Bonneville Power Administration.

<sup>1</sup>By comparison, Oregon's production of construction aggregate in 1988 totaled an estimated 13.6 million tons, worth about \$44 million (U.S. Bureau of Mines preliminary survey).



Harvey O. Banks delta pumping plant, southern area of the Sacramento-San Joaquin delta, California, is shown in the distance. This plant marks the beginning of the California Aqueduct, the largest aqueduct system in the world. Over 8 million  $\text{yd}^3$  of unreinforced concrete was used, and much of the aqueduct is 64 ft wide at the top, 32 ft deep, and 40 ft wide at the base. The average thickness of concrete is about 4 in. Photo courtesy of the California Department of Water Resources.

Inept handling procedures can also be harmful to concrete. Storing a sack of ready-mixed concrete in a damp garage for several years can make it nearly useless, because the cement grains will absorb water, the concrete will take much longer to harden, and it will have reduced strength.

## Aggregate

Poor-quality aggregate can also damage concrete structures. Because about 75 percent of concrete by volume is aggregate, it is critical that clean, hard, and durable sand and gravel be used. Excessive amounts of silt, clay, coal, lignite, and sulfide minerals (such as pyrite,  $\text{FeS}_2$ ; cinnabar,  $\text{HgS}$ ; and pyrrhotite,  $\text{FeS}$ ) in aggregate may stain or seriously weaken the concrete (Kosmatka and Panarese, 1988).

It is also important that aggregate be nonreactive with the cement. Because of its chemistry, portland cement produces a highly caustic solution when mixed with water to make concrete.<sup>2</sup> Nearly all gravels react to some extent with this caustic solution. The reactive alkali content of concrete is commonly denoted by the sodium oxide ( $\text{Na}_2\text{O}$ ) content in the portland cement. On a limited basis, this alkali reaction increases the strength of concrete. However, when the alkali reaction is excessive, the concrete will seriously expand, crack, and lose its integrity.

Aggregates that contain excessive amounts of certain silica minerals will react with the alkali in the cement and damage the concrete. Opal, chert, chalcedony, and other cryptocrystalline quartz minerals as well as some rhyolites and certain other volcanic rocks that contain abundant microfine hydrous silica will adversely react with portland ce-

<sup>2</sup>Because of the caustic chemistry of wet cement, it is desirable to avoid prolonged contact between fresh concrete and skin surfaces. Skin areas that have been exposed to wet concrete should be thoroughly washed with water.

ment, swell in size, and eventually crack the concrete (Legget and Karrow, 1983). If it is necessary to use reactive aggregates for practical reasons, engineers can design sound concrete structures using more expensive sulfate-resistant cement (also called "low-alkali cement").

### ADMIXTURES

Engineers often custom-design specific jobs by including chemical compounds called "admixtures" within concrete. In addition to the commonly used admixtures that accelerate or retard the curing of concrete, many other admixtures can be used in concrete mixes for specific tasks. Admixtures strengthen concrete and make it more resistant to heat and chemical attack and less susceptible to shrinkage and cracking. Researchers in laboratories throughout the world are experimenting with admixtures that will be used to build superior concrete structures. Two commonly used types of admixtures are air-entraining agents and workability agents.



*Hood River Bridge, Hood River, Oregon. Reversing 10° curves were used in this project to connect roads running on opposite sides of Hood River. Approximately 3,000 yd<sup>3</sup> of concrete were used, cast in place and post-tensioned. Photo courtesy of the Oregon Concrete and Aggregate Producers Association (OCAPA).*

### Air-entraining agents

Up to three percent of the volume of standard concrete mixes contain air voids or bubbles that become entrapped by normal mixing methods. In addition, concrete can be foamed with varying amounts of air to make air-entrained concrete. Such concrete has remarkable cost-saving thermal insulation properties and reduces the dead-load weight of concrete structures. However, the most important and most widely used characteristic of air-entraining agents is the resistance to freeze/thaw cycles they give concrete structures.

Water exerts nearly 2,000 pounds of pressure per square inch (psi) as it freezes and expands. Residual amounts of water within the concrete can cause extensive damage through repeated freezing and thawing. The air bubbles in air-entrained concrete give the water enough room to expand as it freezes and vastly improve the resistance of concrete to repeated freeze/thaw cycles. Air-entrained concrete is used to make roads, buildings, and airport runways in regions where icy conditions are common (Kosmatka and Panarese, 1988).

One common method of producing these minute air voids is to add aluminum powder to the concrete mix. The aluminum reacts with the lime and forms very small hydrogen bubbles. When thoroughly mixed, the cured concrete contains evenly distributed bubbles. Other methods of air-entraining concrete are to add synthetic detergents, various sulfonated compounds, and fatty acids (such as oleic acid, C<sub>17</sub>H<sub>33</sub>COOH) to the mixture. Each of these compounds reacts with specific ingredients in the concrete mix to produce bubbles.

Air-entrained concrete contains from 4 to 9 percent air voids by volume, and the air bubbles range in diameter from 0.003 to 0.05 in. One drawback of air entraining is that it reduces the compressive strength of concrete. However, the reduction in compressive strength is generally not more than 15 percent (Kosmatka and Panarese, 1988).

Aerated concrete is related to air-entrained concrete and is a recently developed specialty concrete. It is made by using powdered aluminum to react with cement, water, and additional lime. The mixture is then heated and pressurized with moisture in a large autoclave, causing the concrete to expand and harden within a few hours. The reaction between the powdered aluminum and the lime forms hydrogen gas. The resulting concrete is chemically inert, strong, and so lightweight it can float on water. Aerated concrete has a cellular internal structure and is primarily used for its high thermal-insulation properties. It is also called "gas" or "cellular" concrete (Encyclopedia Britannica, 1984).

### Workability agents

The term "workability" refers to the ease with which freshly made concrete can be placed around reinforcing bars and cables and into tight areas of a form. One of the easiest and most widely used methods of increasing the workability of concrete is to add water; however, this practice lowers concrete strength and durability. Since Roman times, engineers have known that strong, durable concrete requires a low water-to-cement ratio, which makes it stiff and laboriously difficult to place and work. Only the amount of water actually needed for hydration will produce high-strength concrete that is watertight, abrasion-resistant, and durable. As any concrete worker knows, however, handworking a stiff concrete mix can make for a long day.

For the past 20 years, researchers have experimented with a group of admixtures, called "plasticizers," that can increase the workability of a concrete mix without lowering its strength. During the past decade, an improved group of workability admixtures called "superplasticizers" has been developed.

Superplasticizers are important because they significantly increase workability without adding water. They do not harm the concrete. By using superplasticizers to increase workability, the compressive strengths of normal concrete mixtures have more than doubled. Superplasticizers are a family of sulfated organic chemicals, such as sulfonated formaldehyde and lignosulfonic acid, that make concrete soupy.



*Fair Oaks Bridge at Sutherlin, Douglas County, Oregon, a structure that has received a number of awards for its use of concrete. The reinforced-concrete arch bridge uses both precast and cast-in-place concrete. Precasting of the arch ribs and columns saved greatly on forming costs, while the site-cast, post-tensioned deck system allowed the flexibility needed to construct grades and cross-slopes to meet traffic safety requirements. Photo courtesy of OBEC Consulting Engineers, Eugene, Oregon.*





*Concrete state office building in Sacramento, California. The concrete walls are nearly 7 in. thick. The high mass enables the concrete to store and release large amounts of thermal energy. In other words, concrete is used to moderate temperature swings and save on heating and cooling costs. In the hot Sacramento summers, the interior walls absorb and store heat during the day and radiate it at night. The thick concrete walls and floors help maintain a steady interior temperature year-round.*

Research scientists know that superplasticizers somehow change the surfaces of portland cement grains in the concrete, but they do not yet understand exactly how the change takes place. Once researchers fully understand how superplasticizers and other admixtures function, better methods and materials will be used to make concrete structures with vastly increased compressive strengths (Weisburd, 1988).

#### STRUCTURAL CONCRETE APPLICATIONS

Concrete is widely used as a building material primarily because it has tremendous compressive strength. Other important reasons include its versatility, availability, durability, and cost-effectiveness. Structural concrete is so universally used that engineering practices and standards for concrete design are much the same worldwide.

Three common types of concrete used in structures are (1) reinforced concrete, (2) prestressed concrete, and (3) precast concrete.



*Concrete floor panel being placed by means of a tremie line. The concrete was made in a nearby batch plant, transported to the construction site by ready-mix trucks (seen at the base of the building), pneumatically pumped five stories high, and then placed into position by workers.*

#### Reinforced concrete

The advent of reinforced concrete in the 1850's ranks as one of the greatest achievements in civil engineering. Because of its weak tensile strength, nearly all concrete used in construction is reinforced with steel bars, rods, and, more recently, synthetic and steel fibers. These reinforcing materials are bonded to the surrounding concrete so that stresses are transferred between the two materials.

Strength of concrete and its reinforcing materials determine the load-carrying capacity of concrete structures. Reinforcing materials are generally not needed for relatively simple concrete projects, such as concrete sidewalks or residential driveways. However, for large structures (buildings and bridges) that must sustain intense stresses, reinforced concrete is required.

Steel rebar is the most commonly used reinforcing material in concrete. Because concrete and steel undergo about the same amount of thermal expansion, they can be used together without fear of cracking and weakening the structure. Reinforced concrete structures require less maintenance than steel or wooden structures and are frequently less expensive to build. When large structures are needed in remote regions, architects and engineers generally prefer reinforced concrete over other materials because it is more practical.

It is important that rebar adheres firmly to the concrete. To increase the bond, rebar is ribbed and sometimes allowed to corrode in air, so that its steel surface will have a rough texture.

Marine concrete facilities, such as harbors, can be significantly damaged by corrosion from seawater. Chlorine in the seawater chemically attacks the steel rebar in the concrete, seriously weakening the structure. Since the 1970's, epoxy-coated rebar has been successfully used in marine facilities for protection against damage from corrosion. Epoxy-coated rebar reduces the corrosion rates by 41,000 percent and is impervious to moisture and chlorine ions.



*Ten-story building in San Francisco, California. Prestressed concrete panels were used on the exterior cladding because of their low weight, uniformity, and sharp profiles. Advances in concrete continue to expand its versatility. Photo courtesy of the Prestressed Concrete Institute.*



Construction of the San Diego, California, aqueduct in 1976. Each prestressed concrete-pipe section is 8 ft in diameter and weighs 40 tons. The aqueduct is being placed on a 55° slope near Fallbrook, California. Photo courtesy of Ameron.

### Prestressed concrete

As useful as reinforced concrete is, under a heavy load, long-beam supports will bend downwards, as shown in diagram on right, section (A). Engineers have devised a resourceful solution to this serious drawback by intensely stretching high-strength steel cables before the concrete bonds to them. After the concrete is poured and allowed to harden, the force that produces the stretch in the steel cables is released, and the concrete becomes compressed, as shown in diagram sections (B) and (C).

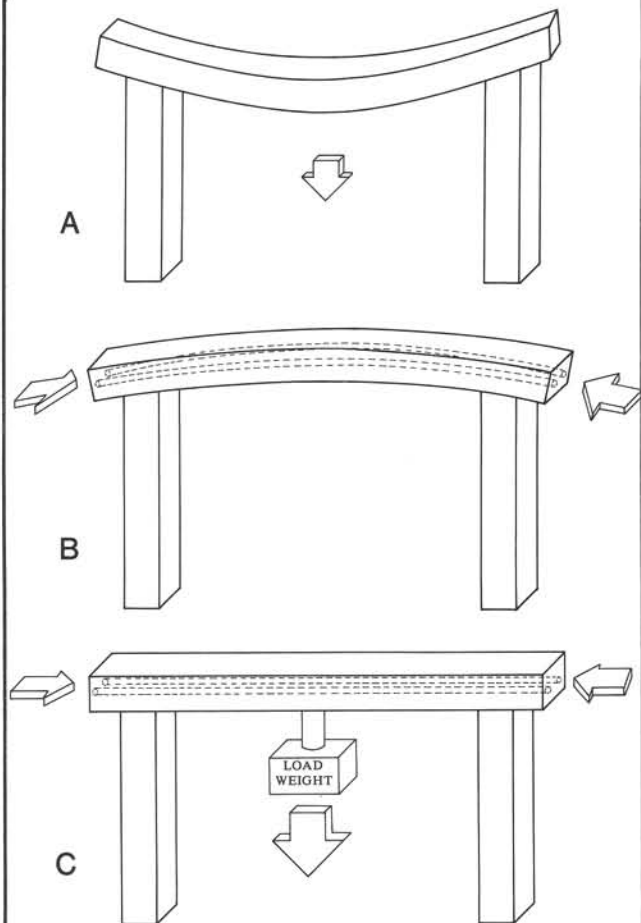
The primary reason for prestressing concrete is to give long-span beams great strength while at the same time lessening the thickness of the beam. Prestressed concrete beams are able to support very heavy loads and are engineered to precise specifications.

The force of the cables tends to warp the beam, similar to the way a bow is arched (diagram section B). When the beam is placed into position and load weight is applied, the downward force merely serves to reduce the bowing effect (diagram section C). As a result, the strength of the beam under load is immense. The stresses imposed on the reinforcing rods are engineered to be larger than any load weight applied to the beam. In diagram section (C), the load weight on the beam is placed beneath it for descriptive purposes. In practice, engineers use prestressed beams tailor-fitted to support load forces that act on the beam from any conceivable orientation (Waddell, 1976; McGraw-Hill Encyclopedia of Science and Technology, 1987).

Two general methods of stressing concrete are used: (1) pretensioning concrete and (2) post-tensioning concrete. High-quality steel cable is used in these stressing methods because of its great strength. In the pretensioning method, steel cables are placed under tension by stretching them with great force at both ends with hydraulic jacks.

### PRESTRESSED CONCRETE

Concrete is strongest when it is compressed. Steel is strongest when it is stretched (placed in tension). These two parameters are combined in prestressed concrete.



(A) Used by itself, concrete makes an unsatisfactory beam support because it has weak flexural strength. Over time, the weight of the concrete beam alone will cause it to slump and crack.

(B) High-strength steel cables stretched with intense force are incorporated into the concrete beam, placing it under compression. Cables are placed so that the force they exert slightly arches the beam upward. In this way, the combination of the compressive strength of concrete and the tensile strength of steel cables gives the beam tremendous strength.

(C) When dead-load weight is placed on the beam, the downward force of the load merely serves to reduce the bowing effect.

The concrete beam is poured (or "cast") around the cables in the normal way. When the concrete hardens, the tension placed on the cables by the hydraulic jacks is released. The prestressing force in the steel cables is transferred to the surrounding concrete, and the concrete is placed under compression.

In the post-tensioning method, a reinforced concrete beam is cast and hardened with holes or channels passing through it. After the concrete has completely set, steel cables called "tendons" are threaded through the channels, placed under extreme tension by hydraulic jacks, and anchored to the end of the beam or slab.

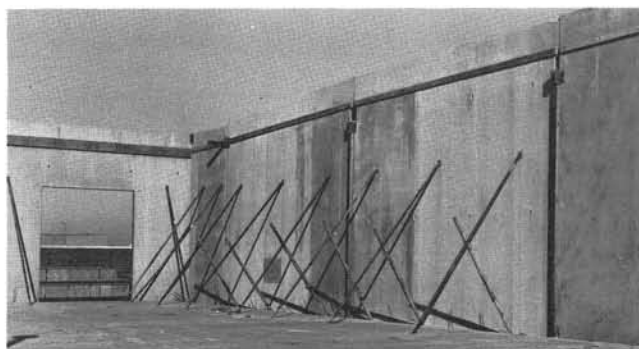
Structures that incorporate prestressed concrete are more costly than normal reinforced concrete structures because of the high-strength steel cables and increased labor costs. Steel cables used in prestressed



Carpenters making the forms for precasting panels for a tilt-up building. The 7-in. concrete panels will be cast on the completed concrete floor slab, then lifted (or tilted) by crane into a vertical position. Door frames are positioned before casting. Since World War II, the manufacture of tilt-up buildings has steadily increased because they are practical. The main advantage of tilt-up buildings is the elimination of vertical formwork for the walls.



Precast concrete panels for the tilt-up building with the forms removed. The rebar and bolts embedded in the concrete add strength.



The 22-ft-tall panels lifted into place and temporarily supported by 2-in.-thick steel rods embedded in the concrete. After the panels are bolted together and the base is cast and hardened, the rods will be removed.



The finished product. Tilt-up buildings are cost effective, long lasting, and relatively fast to construct.

concrete typically have minimum tensile strengths of 270,000 pounds per square inch for diameters of 0.25 in. Precise construction practices and close monitoring are required to manufacture prestressed concrete members and structures. Such structures can withstand very great forces and are frequently used in bridges, large storage tanks, tunnels, high-rise buildings, and dams (Waddell, 1976, 1985; McGraw-Hill Encyclopedia of Science and Technology, 1987).

#### Precast concrete

Second in tonnage to ready-mix concrete is the production of precast concrete. Concrete sewer pipes, blocks, wall panels, beams, trusses, and girders are first cast in a fabrication yard, allowed to harden, and then trucked to the building site. Nearly all prestressed concrete structures are precast. Very heavy concrete structures, such as concrete floor, roof, and wall panels, are commonly precast, allowed to harden at the building site, and then hoisted by cranes into position. Advantages of precasting concrete are that it (1) allows for better quality control; (2) enhances architectural design; and (3) is often more economical and efficient, because the casting can be done away from the construction site.

#### SPECIALTY CONCRETES

More than 50 kinds of specialty concretes made with portland cement are used in the United States. Specialty concretes have unusual properties that are used for specific purposes. Four common specialty concretes are (1) lightweight concrete, (2) heavyweight concrete, (3) fiber-reinforced concrete, and (4) high-strength concrete.

#### Lightweight concrete

Lightweight concrete is similar to normal-weight concrete except that it is made with aggregates that have low densities. It is primarily used to reduce the dead-load weight in concrete structures. Compared with the weight of normal concrete, which ranges from 130 to 155 pounds per cubic foot, lightweight concrete weighs from 85 to 115 pounds per cubic foot. A frequent use of lightweight concrete is in high-rise office floors. Pumice, scoria, vermiculite, perlite, and specially fired shales and clays are used in this type of concrete instead of the usual sand and gravel (Kosmatka and Panarese, 1988).

#### Heavyweight concrete

Concrete made with heavy materials, such as steel aggregate, is used for radiation shields in nuclear power plants. Heavyweight concrete normally weighs from 200 to 360 pounds per cubic foot. Goethite (specific gravity 3.4 to 3.7), barite (specific gravity 4.0 to 4.6), and limonite (specific gravity 3.4 to 4.0) are suitable for use in the lower weight ranges; hematite (specific gravity 4.9 to 5.3), magnetite (specific gravity 4.2 to 5.2), and ilmenite (specific gravity 4.3 to 4.8) for the medium-weight ranges; and steel punchings (specific gravity 6.2 to 7.8) are used in the upper-weight ranges (Kosmatka and Panarese, 1988).





*Award-winning private residence in Salem, Oregon, built with precast, lightweight, cellular concrete made of sand, cement, and foam. The new material allows easy handling, sawing, even nailing with regular nails. It also is rot- and termite-proof, resistant to fire, and has good sound-proofing and insulating qualities. This home also won an Oregon State Award based on energy efficiency, cost, and marketability. Photo courtesy of OCAPA.*

Powdered, lighter weight strontium and borate minerals, such as colemanite and borocalcite, are sometimes used in heavyweight concrete to aid in absorbing X-rays and gamma rays. The strength of heavyweight concrete is comparable with normal structural concrete.

#### **Fiber-reinforced concrete**

The corrosion problems encountered with steel rebar prompted the development of fiber-reinforced concrete. Fibers of steel, natural cellulose, glass, carbon, fiberglass, polypropylene, and bamboo are used. The fibers typically are round, flat, or crimped and range in length from 0.25 to 3 in. Content of fibers in concrete is typically 2 percent by volume but may range up to 14 percent when steel fibers are used (Kosmatka and Panarese, 1988).

Advantages of the use of fiber-reinforced concrete are that it (1) reduces construction time by reducing the amount of rebar needed, (2) increases impact resistance, (3) lessens permeability, and (4) prevents microcracks that are common in concrete.

Fiber-reinforced concretes are effectively used in applications that do not require constant heavy stress, such as in airport runways and floors in skyscrapers. The increased structural support this specialty concrete provides in tight areas where reinforced rebar concrete cannot be placed is an added benefit.

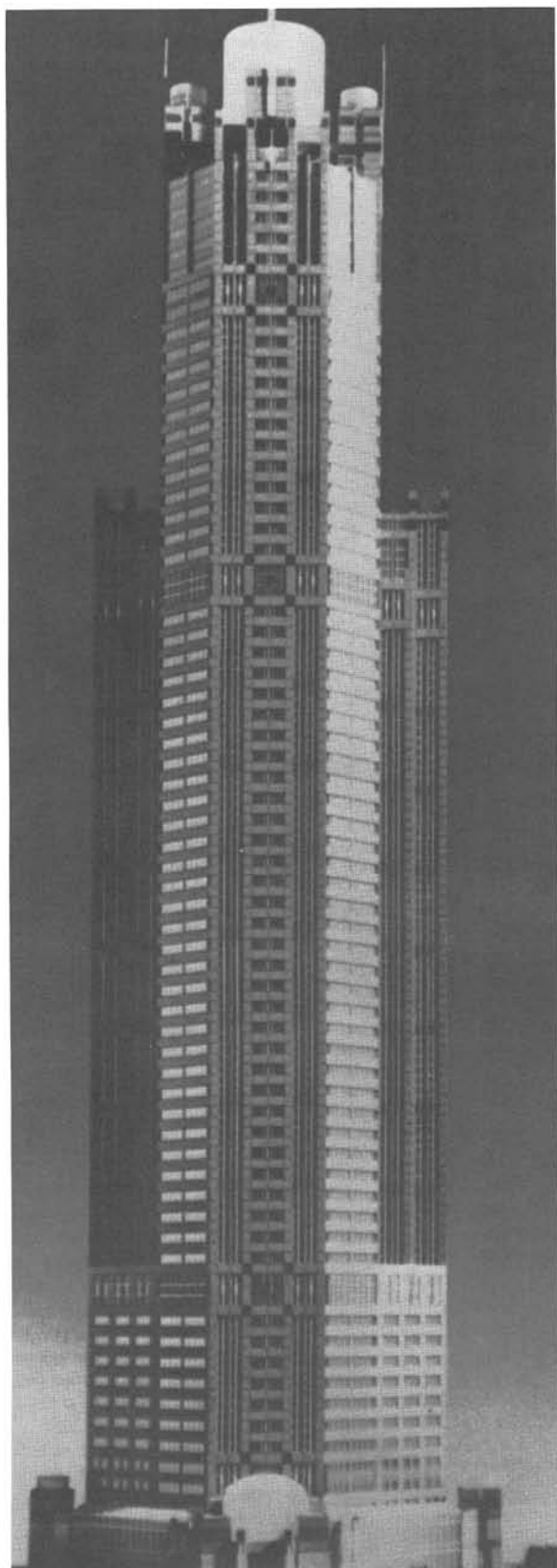
#### **High-strength concrete**

Compared with normal concrete that has unconfined compressive strengths ranging from 2,500 psi to 5,000 psi, high-strength concrete is generally defined as having a compressive strength in excess of 6,000 psi. Superplasticizing admixtures are commonly added to high-strength concrete mixes to increase workability. Tough, durable aggregate is also needed. Just a few years ago, 10,000-psi concrete was considered noteworthy; today, engineers are using 19,000-psi concrete,



*Airport control tower at Mahlon-Sweet Airport in Eugene, Oregon. Precast concrete is used in this construction, and the design can easily be repeated at other locations. Photo courtesy OCAPA.*





*Model of the Wacker Drive Building, Chicago, Illinois. When completed by the end of this year, at 946 ft high, it will be the tallest concrete building in the world. The size of this building is made possible by the use of high-strength concrete. Photo courtesy of Kohn, Peterson, and Fox.*

and researchers predict that near-future concrete mixes will have compressive strengths over 30,000 psi (Godfrey, 1988). Mathematical models exist for 40,000-psi concrete.<sup>3</sup>

The use of high-strength concrete has increased in recent years. High-strength concrete costs more than conventional concrete, but less of it is needed. Combined with stronger lightweight aggregates, high-strength concrete reduces the dead-load weight in buildings and increases usable floorspace while reducing column and beam size. With the development of stronger and lighter concrete, engineers are using innovative designs to build taller concrete skyscrapers and stronger bridges, tunnels, dams, and other structures.

High-strength concrete is frequently used where large stresses are anticipated, as in skyscrapers. For example, the tallest concrete building in the world is currently being constructed in Chicago using high-strength concrete. Known as the Wacker Drive Building, much of the estimated 110,000 yd of concrete used in its construction will have compressive strengths of 12,000 psi. When the \$110-million skyscraper is completed in 1989, it will have 50 floors and will be 946 ft high. Only ten steel-framed buildings will be taller than that in North America. Because it is cheaper, reinforced and prestressed concrete instead of the more traditional steel frame is being used to construct this skyscraper. Building costs will be reduced by several million dollars (ENR, 1988; Robison, 1988).

Another notable concrete building, the Two Union Square Building in Seattle, Washington, is being built using the highest strength concrete ever employed in a conventional building. Much of the 720-ft-high building will incorporate 19,000-psi concrete, nearly four times the strength of normal structural concrete. Superplasticizers and quartzose aggregate are used in the concrete mix (Godfrey, 1988).

Other applications of high-strength concrete include using 20,000-psi concrete in recently constructed bank vaults and prestressed beams. More than ten years ago, 15,000-psi concrete was used in missile silos. Higher strength concrete is currently being used to build similar military facilities.

## TECHNOLOGY

A variety of new products is being developed, such as fibrous, polymer, and polymer-impregnated concretes. These new materials are lighter, stronger, more resistant to heat and chemical attack, and more impervious to fluids than traditional types of concrete.

### Polymers and epoxies

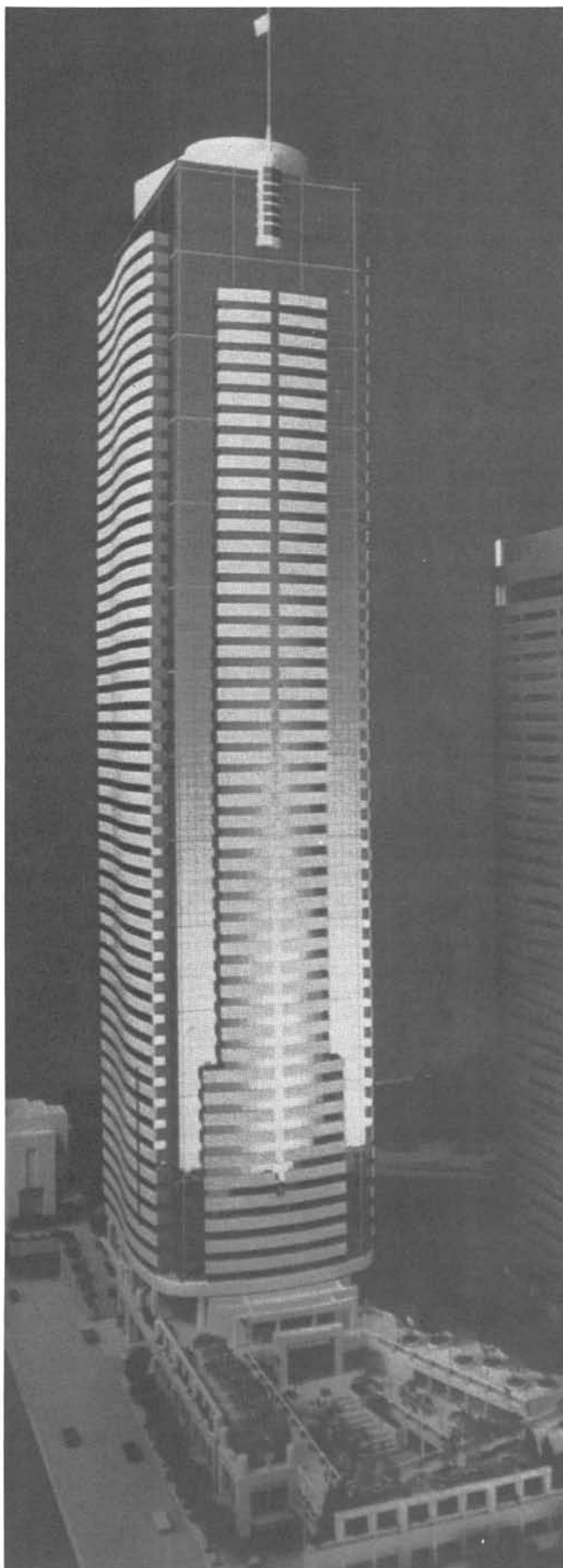
Synthetic polymers and epoxies are used in limited quantities primarily for repairing damaged concrete structures. Polymers are very large molecules that are composed of repeated motifs of smaller molecules. Examples of common polymers include plastics and synthetic fibers, such as rayon, orlon, polyethylene, and fiberglass. Epoxies are a class of thermoplastic polymers (they become soft when heated and hard when cooled). Epoxies, also called "epoxy resins," are chemically inert and strong adhesives. When polymers and epoxies are properly placed in damaged concrete, the repaired portions are often stronger than the surrounding concrete.

Polymer-impregnated concrete is made by heating the damaged concrete structure to remove any residual moisture. Heated polymer plastic is then forced under intense pressure into the air voids that ordinarily occur in concrete. In polymer concrete, monomer and polymer resins entirely replace the portland cement. Polymer-impregnated concrete and polymer concrete are used to a limited extent in patching and repairing concrete structures and for some road-pavement surfaces. Epoxy adhesives are primarily used to repair concrete structures and to strengthen precast concrete segments.

## RESEARCH

In the future, architects and engineers will use new techniques and improved concretes that are currently being developed. Advanced con-

<sup>3</sup>For comparison, the compressive strength of granite is about 22,000 psi, and the compressive strength of basalt is about 25,000 psi.



*Model of the 759-ft-high, 62-story Two Union Square Building currently under construction in Seattle, Washington. It is being built with the strongest concrete ever used in a conventional building. Some columns have been fashioned with 19,000-psi high-strength concrete. In 1947, construction concrete had a compressive strength of 3,500 psi. By 1960, 5,000-psi concrete was being used, and today 12,000-psi concrete is frequently used. Researchers predict that by the year 2000, 25,000-psi concrete will be available. Photo courtesy of Skilling Ward Magnuson and Barkshire.*

crete-based materials have already begun to augment and replace more conventional building materials such as wood, tile, brick, and steel.

On the surface, portland cement concrete appears to be a simple material. Its internal structure, however, is very complex. In research laboratories, scientists are only now beginning to understand the complex chemical reactions that occur as common concrete hardens. Iridium and platinum crucibles are used to minimize contamination in the experimental concrete mixtures.

To better understand the internal structure of concrete and how it forms, researchers in Belgium and England conducted experiments using heavy water (deuterium oxide,  $D_2O$ ) instead of normal water to make concrete. The heavy water permits neutron scattering analyses that yield information about the microstructure of the concrete. Because heavy water costs more than \$4,000 per pint, this may have been the most expensive concrete ever made (Hansen, 1982).

## CONCLUSION

Concrete has enhanced the quality of our lives and will continue to do so far into the future. Experts predict that concrete will become lighter and stronger, and its use in long-span bridges, high-rise buildings, highways, and myriad other applications will increase. The versatility and multifunctions of concrete have captured the imagination of architects, engineers, and research scientists. Architects will continue to design concrete structures with enhanced, eye-appealing colors and textures that promote the technical artistry of concrete. Engineers will find innovative uses for improved specialty concretes, and research scientists will develop superior concrete-based materials.

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# A note on the origin of Bull Run and Lost Lakes, Western Cascades, Oregon

by David R. Sherrod and Leda Beth G. Pickthorn, U.S. Geological Survey, Menlo Park, CA 94025

We were pleased to read Allen's (1989) description of the evidence for glaciation in the Western Cascades subprovince of the Cascade Range near the Columbia River. We add a twist to the story of Bull Run Lake, which is in Portland's Bull Run Watershed, Mount Hood National Forest, and clarify the setting of Lost Lake, which is located about 3 km to the north.

Allen was correct in describing the basin of Bull Run Lake as a cirque in the U-shaped upper part of Bull Run canyon. However, the natural dam is not of glacial origin, as suggested by Allen. Instead, it formed when a landslide moved off the northeast canyon wall near Preacher's Peak (Figure 1). The resulting hummocky ground is underlain by jumbled and broken basalt. Wise (1969) thought that the irregular terrain and abundance of fresh lava indicated a Quaternary lava flow. In his interpretation, the flow had to be relatively young—latest Pleistocene or Holocene—to have escaped excavation by late Pleistocene glaciers. Although we have not dated the lava in the landslide or near Preacher's Peak, its age is probably about 2 Ma, on the basis of a K-Ar age of  $2.54 \pm 0.80$  Ma (Table 1) from stratigraphically similar basalt lava near Thimble Mountain, 8 km southwest of Bull Run Lake. The landslide must be latest Pleistocene or Holocene in age, because it is unglaciated.

According to Allen (1989), Lost Lake was dammed by lava from Lost Lake Butte, a small (1.2 km<sup>3</sup>) basaltic shield volcano (Wise, 1969). We agree that Lost Lake's basin results from the fortuitous position of surrounding ridges and Lost Lake Butte, but the basin is closed,

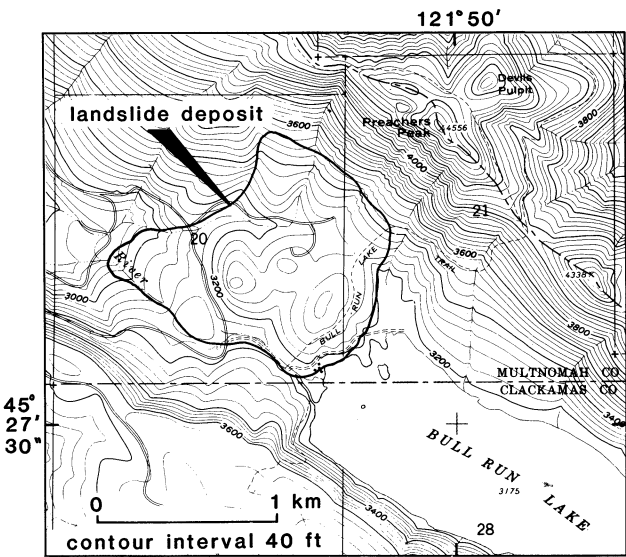


Figure 1. Map showing landslide deposit at mouth of Bull Run Lake. Base from U.S. Geological Survey, 1962.

Table 1. Whole-rock K-Ar age of basalt from Thimble Mountain, 43°9.5' N., 122°4.0' W., Hickman Butte 7½-minute Quadrangle, Oregon.

Sample number <sup>1</sup>	K <sub>2</sub> O (wt %) <sup>2</sup>	<sup>40</sup> Ar <sub>rad</sub> (10 <sup>-11</sup> moles/g)	Percent <sup>40</sup> Ar <sub>rad</sub>	Calculated age (Ma) <sup>3</sup>	Assigned age (Ma) <sup>4</sup>
S5-47	(1.619)				2.54±0.80
	1.612	0.5998	41.0	2.57	
	1.608	0.5860	46.6	2.51	
	1.633				
	1.624				

Notes:

<sup>1</sup>Sample preparation and analytical work were done at U.S. Geological Survey by LedaBeth G. Pickthorn.

<sup>2</sup>Value in parentheses is arithmetic mean used in age calculation.

<sup>3</sup>K-Ar ages were calculated using the constants for the radioactive decay and abundance of <sup>40</sup>K recommended by the International Union of Geological Sciences Subcommittee on Geochronology (Steiger and Jager, 1977). These constants are:

$$\lambda_E = 0.580 \times 10^{-10} \text{ yr}^{-1}, \lambda_\beta = 4.962 \times 10^{-10} \text{ yr}^{-1}, \text{ and } ^{40}\text{K}/\text{K}_{\text{total}} = 1.167 \times 10^{-4} \text{ mol/mol}$$

<sup>4</sup>Weighted mean of age from two extractions.

and the lake is impounded by ground moraines that fill a broad marshy area at its north end and choke a shallow drainage divide at the southeast end.

As an aside, Lost Lake Butte is older than latest Pleistocene glaciation, as indicated by two small cirques northeast of its summit. The morphology of the shield is characteristic of volcanoes younger than about 250,000 yr B.P.; older Cascade Range volcanoes are generally deeply gutted by glaciation. Lost Lake Butte may be much younger than 250,000 yr B.P., but presently there are no absolute ages with which to calibrate the progressive stages of erosion in young basalt or basaltic andesite shield volcanoes of the Cascade Range.

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# Geophysical exploration: The first step in the search for new petroleum supplies

by Charles F. Darden, President, International Association of Geophysical Contractors, P.O. Box 460209, Houston, Texas 77056-0209

This is one of a series of articles on the oil and gas industry that have been written for *Oregon Geology* by people who work in various occupations within the industry itself. This particular article describes some of the geophysical techniques used in the exploration for and development of oil and gas resources. Earlier articles in this series included discussions of how oil and gas form and how wells are logged after they have been drilled. Future articles on the oil and gas industry will appear at irregular intervals in upcoming issues of *Oregon Geology*.  
—Editor

## INTRODUCTION

With the cost of drilling an exploratory well in search of crude oil and natural gas supplies exceeding a million dollars in nearly all cases, geophysical exploration (primarily the seismic method) continues to increase in importance because it substantially improves the success rate of this effort. Additionally, seismic surveys are increasingly being used to help maximize production in known petroleum reservoirs.

Exploration geophysicists gather and analyze seismic, gravitational, magnetic, and other data to learn what minerals are in the earth and what are the shape and properties of subsurface rocks. From these data, they trace the sequence of rock layers and decide on the likelihood of finding oil in a particular onshore or offshore location. Derived from physics, one of the oldest branches of science, geophysics has become an integral part of the worldwide effort to find new petroleum supplies.

More than 40,000 professionals and technicians are employed in the United States alone as part of the geophysical exploration "team." Worldwide expenditures for the acquisition, processing, and interpretation of geophysical data as part of this process totaled \$1.5 billion in 1987. While this highly complex business, which performs the first step in the petroleum exploration effort, often has very limited visibility, it is in fact a major industry in itself. For most people who encounter the industry, the only component they usually see is the seismograph field crew working in their localized area.

## GEOPHYSICAL TOOLS

The seismograph provides the only direct way of acquiring subsurface structural information without drilling wells, and its success in supplying this information continues to increase through ever-evolving technological advances. Soundlike waves called "seismic acoustic waves" generated at or near the surface penetrate the earth's crust and reflect from subsurface rock levels back to the surface. There the reflected signals can be recorded, just as is done with radar. The geophysicist receives a printed record, called a "seismogram," from which he or she can measure the depth of various strata. When a series of seismic shots is made over a considerable distance, the resulting succession of seismograms shows a cross-section of the subsurface. Ideally, such a section reveals patterns of the strata below, such as faults, anticlines, folds, and other subsurface structures that might be oil- or gas-bearing.

In the industry's early days, dynamite was used almost exclusively for generating seismic waves, but today, mechanical sources of wave energy such as earth vibrators are also used. In one widely used vibratory technique called "shaking" rather than "shooting," a unit mounted on a truck or boat creates seismic waves by means of a vibrator pad that is lowered to the earth (or water when used offshore). In contrast to the ruggedness of the instruments used to create seismic energy, the seismometers used to "hear" seismic reflections (known as "geophones" when used on land and "hydrophones" when used at sea) are extremely sensitive instruments—so sensitive, in fact, that they are capable of detecting a strong coastal wind or a

person walking on the surface a quarter of a mile away. Seismometers (commonly called "jugs" in industry jargon) are usually strung out in long lines, connected by electrical cables extending over the exactly surveyed seismic line, and placed directly on the ground. A similar process that will be discussed later takes place for marine operations.

Each seismometer picks up the signals bouncing off many layers of the subsurface and produces its own seismic "trace," which is recorded both on sensitized paper and on magnetic tape. The amount of time it takes for a seismic wave to bounce back from the various strata gives the geophysicist a clue to the depth of each rock layer. Improvements in digital recording instruments have vastly improved the geophysical industry's ability to record and play back seismic data collected. New computing methods and electronic equipment used to play back seismic recordings continue to overcome many of the noise and geophysical interpretation problems to make seismic exploration more valuable. Also, computerized display equipment now makes it possible to compress wide areas of seismic exploration into desk-size sections that can be more easily analyzed.

For many years, geophysicists have collected data along linear cross-sections of the earth. These surveys provided information beneath the survey line, which was usually displayed as a two-dimensional "slice" of the subsurface. Recently, seismometers have been distributed over a wider area on the earth's surface, and information has been collected throughout a volume of the subsurface. This acquisition method is called "three-dimensional" or "3-D" shooting. It provides a tremendous amount of information that can be analyzed only by powerful computers. Its use now enables drilling locations to be determined with greater confidence. Three-dimensional shooting is used not only as an exploration tool but also in exploitation or production work.

## OTHER GEOPHYSICAL TOOLS

In addition to the seismograph, other tools are widely used by geophysicists to measure the various characteristics of the earth as part of the petroleum-finding effort. Of these, the best known are the magnetometer and the gravimeter. However, it should be noted that about 95 percent of the dollars spent on exploration geophysics involves the seismic method.

The magnetometer is an instrument that measures variations in the earth's magnetic field caused by changes in the magnetic properties of subsurface rocks. Resembling a large camera, the magnetometer is used both on the ground and in the air to accurately measure magnetic intensity. Each of the earth's three major classes of rocks—sedimentary, igneous, and metamorphic—have different magnetic properties according to their iron content. Sedimentary rocks associated with oil and gas generally have lower magnetic properties than other rocks.

The gravimeter, on the other hand, literally weighs the earth. It can detect variations in the gravitational pull of rocks that lie as much as several miles below the earth's surface. Because large masses of dense rock increase the pull of gravity, gravimeter readings at



them with agreements made in new areas. Sometimes the permit agent travels hundreds of miles a day and may be days or weeks ahead of the actual seismic operation.

### Surveying the route

Next comes the survey crew, which marks the exact route the seismic line will take. The survey crew also measures surface elevations along the line and specifies the points where sound waves will be generated and listening devices placed.

### Laying out geophones and recording equipment

Following the surveyors, another part of the instrument crew pays out sensitive listening devices along the seismic line. These geophones pick up the reflected sound waves after they have been weakened by passing through miles of underground rocks. The geophone converts these signals into electric impulses that are transmitted by cable to the recording truck. Inside the truck are delicate electronic instruments that amplify and record the electric impulses for later computer analysis. Geophones and recording instruments are so sensitive that they can pick up footsteps scores of feet away.

### Generating energy waves and recording data

Seismic waves may be generated several waves into the ground. Commonly used methods include surface detonations, shot-hole detonations, vibroseis, and air guns. Special equipment used and procedures followed for these four methods are discussed later in this paper.

### Cleaning up the site

While seismic crews move rapidly from area to area, they exercise care to clean up along the seismic line so the area is left as near to its original condition as possible. The permit agent or another representative of the crew coordinates this effort to make sure that all the terms of the permit have been satisfied.

## VARIED LAND SEISMIC ENERGY SOURCES

Illustrated below are the four most common methods for generating sound waves for land seismic exploration: surface detonations, traditional shot-hole operations, the vibrating energy source, and the air gun. Factors that influence the selection of a particular method include prior experience, environmental concerns, and economics. Whenever possible, exploration companies prefer to have flexibility in selecting the best method to be sure they obtain the highest quality geophysical data.

### Surface detonations

Often specified by government permitting agencies in remote areas away from people is the "surface shooting" method. This is



Explosive charges for surface detonation are mounted on wooden stakes above the ground.

usually a portable operation, with helicopters used to transport workers and equipment along the survey line, avoiding the use of motorized vehicles and ensuring minimum impact on the land.

Small charges are mounted on wooden stakes several feet above the ground in a pattern that could include from one to a dozen charges at each shot point. The detonation of these surface charges can be heard for a considerable distance, depending on such factors as surface terrain and weather conditions. However, the sound level is relatively low, and incidences of actual physical damage or serious disturbance of wildlife are extremely rare.

### Traditional shot-hole operations

In this method, a hole is drilled, and an explosive charge is buried. Detonation of the buried charge creates a seismic sound wave. The typical seismic shot hole ranges from 10 to 200 ft in depth and is about 4 in. in diameter. Detonations are usually contained within the hole to force the energy generated downward through various rock strata, and the only sound that can be heard above the ground is a dull thud.



A shot hole is drilled, and an explosive charge is buried and later detonated to create a seismic sound charge.

### Vibrating energy source

The vibroseis method involves surface vibration rather than detonations. A specially designed vibrator pad, mounted below a vehicle, is compressed against the ground and vibrated at regular intervals to create sound waves. Damage to the ground by vibrator pad is minimal. Several of these vehicles operate together to form the energy source. Difficult terrain often limits the use of this particular seismic energy source.



Specially designed vibrator pads located beneath the trucks are vibrated to create sound waves for the vibrating energy source method of exploration.

### Air-gun operations

An air gun is a truck or tractor-mounted seismic source that uses compressed air. The air gun is contained inside a bag filled with water and discharges compressed air, which generates the seismic sound waves. The air-gun bag is mounted on the back of a truck. Damage to the ground by the bag is minimal. Up to four air-gun trucks may operate together for most seismic exploration work. This source is also limited by terrain and data-quality considerations.



*An air gun using compressed air inside a bag filled with water is mounted on this truck and discharged to generate seismic sound waves.*

### OFFSHORE GEOPHYSICAL SURVEYS

Geophysical exploration activity also has been extensively adapted to the offshore environment. Modern seismic vessels are designed specifically for surveying, as is the equipment to interpret and refine the data received. But, instead of using the same equipment that is used onshore, such as "surface shaking" machines and geophones, seismic crews offshore generally use chambers, or air guns, containing compressed gases or fluids to generate the acoustic signals and hydrophones to pick up the returning sounds.

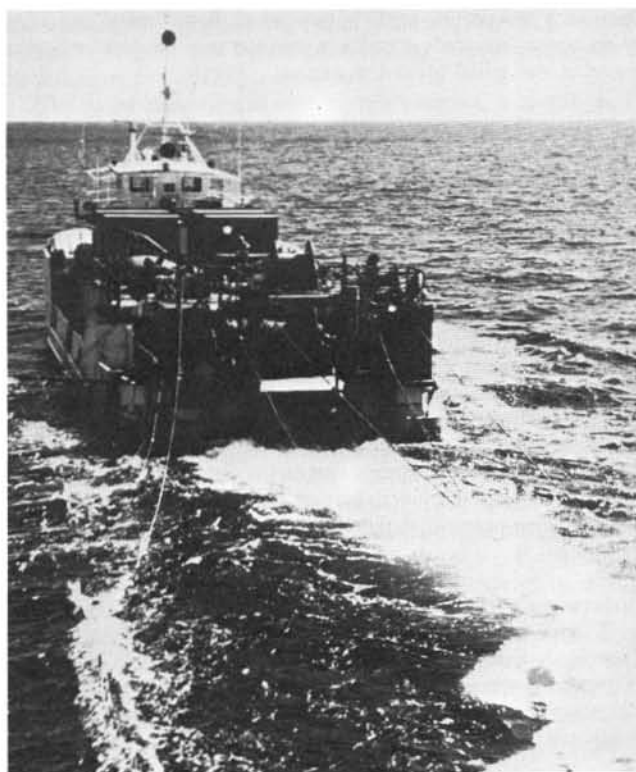
These confined "explosions" leave only air bubbles and a muffled thumping sound to attest to their presence and use. The chambers are trailed behind the vessel as it moves along a predetermined survey line. The crews activate the chambers at set intervals from onboard controls connected by cables to the energy source. Other cables contain arrays of hydrophones that receive the sounds created by the explosions as they echo off the underlying strata beneath the sea and transmit that information to the inboard seismograph and computers.

Prior to and throughout the survey, great care is taken to alert fishing or other vessels in the area to the presence of the survey vessel and its course. Sophisticated collision avoidance equipment is standard aboard modern seismic vessels. The vessels are kept on course through use of radar, loran, and satellite navigational equipment.

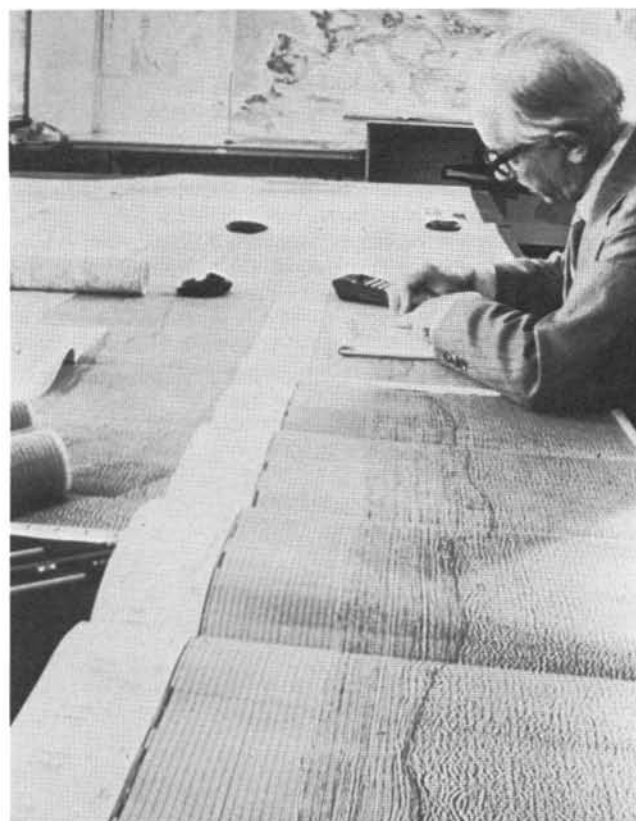
Other instruments keep track of the cable containing the hydrophone—the "streamer"—which may extend for nearly 2 mi behind the vessel. In sensitive fishing areas, marine biologists may accompany the seismic crews to monitor operations.

### IMPORTANCE OF SELECTION OF SEISMIC ENERGY SOURCE

In both land and marine geophysical operations, subtle differences exist in both data-acquisition and data-processing techniques used by different companies. Individual companies select what they con-



*Marine geophysical vessel towing (1) air guns that release compressed air to generate pressure impulses, and (2) hydrophones that receive the reflected signal generated by the air guns.*



*Geophysicist interpreting a seismic section composed of offshore reflection data.*

sider to be the best seismic energy source that yields the highest quality data and is compatible with environmental and other goals. These differences in techniques of exploration companies contribute to the industry's overall success in locating new drilling prospects that otherwise would have been missed if only one survey had been conducted in the area and perhaps the wrong energy source was employed the first time.

When industry first has exploration interest in a particular region, a broad reconnaissance is done, and then the grid of survey lines is steadily tightened to target places where the data suggest favorable conditions exist. This goes from lines as far apart as 50 mi to as close as half a mile or less. Each time data are collected, the industry learns more about an area.

## TRENDS IN GEOPHYSICAL EXPLORATION

In the United States, land acquisition for oil and gas exploration and development has declined over the last few years, and the main interest has moved offshore, in most cases to the Gulf of Mexico. Furthermore, exploration efforts are shifting more and more from the United States to other parts of the world, primarily the North Sea and the Far East, followed by West Africa.

Geophysical work in the oil industry is also changing, from exploration for new fields to development of existing fields. Five years ago, 90 percent of geophysical work in the oil and gas industry was in exploration. Today, more than half of the activity is funded from oil and gas companies' production budgets. □

## Field trip guides for IGC offered

More than 7,500 geoscientists from at least 100 countries will meet in Washington, D.C., this summer, July 9-19, at the 28th International Geologic Congress (IGC). This is the first time in more than 50 years that this important gathering has been held in the United States. The IGC has met about every four years since the 1800's.

The written record of the Congress will consist of field trip guidebooks, short-course books, and abstracts. Field trip guidebooks and short-course books are now being offered for sale by the American Geophysical Union (AGU).

The field trip guidebooks cover distinct geographic regions and are written for the nonspecialist who has a geologic background. They contain road logs, describe geologic features, provide historical information, discuss the geologic processes operating in the region, and are illustrated with drawings, photos, and geologic maps. A total of approximately 130 field trip guidebooks will be available, ranging in length from 4 to 216 pages and in price from \$6 to \$35. Specially priced compilations are also offered. For IGC field trip participants, the cost of guidebooks is included in the trip fee. With one exception (Antarctica), the guidebooks will be released for sale after June 30.

Included among the field trip guidebooks for the western United States are the following:

- Snake River Plain-Yellowstone volcanic province (T305);
- Cascade Range (T306)
- Accreted terranes of the North Cascade Range, Washington (T307)
- Geologic evolution of the northernmost Coast Ranges and western Klamath Mountains, California (T308)
- Glacial Lake Missoula and the Channeled Scablands (T310)
- South Cascades arc volcanism, California and southern Oregon (T312)
- Cenozoic volcanism in the Cascade Range and Columbia Plateau, southern Washington and northernmost Oregon (T106)

Short-course books contain material from special classes that will be given during the IGC. The courses will cover such subjects as past and future climate, volcanic hazards, modeling ground-water flow,

sedimentary-basin analysis, hydrothermal systems, and paleoenvironment.

For information about the IGC, contact Bruce B. Hanshaw, Box 1001, Herndon, VA 22070-1001; phone (703) 648-6053.

More information on the AGU publications is available from Alan Tourtlotte, AGU (address and phone below).

For book orders, contact AGU—Orders, 2000 Florida Avenue, NW, Washington, D.C. 20009. Call 1-800-424-2488 toll free or (in D.C. or outside the U.S.) AGU at (202) 462-6900. Electronic mail: Cust.Service/Edunet/Kosmos. Fax: (202) 328-0566.

—From AGU news release

## Reports on five Gorda Ridge studies released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released five reports presenting results of research on the Gorda Ridge, a sea-floor spreading region off the coast of southern Oregon and northern California. The reports, published as DOGAMI open-file reports, add more information to the ongoing research into the extent, nature, and effects of the hydrothermal venting that occurs along the mid-ocean ridge.

The studies were connected with two diving expeditions conducted in 1988—of the submersible *Alvin* in June and of the submersible *Sea Cliff* in September. They were part of a research program that was directed by the joint federal-state Gorda Ridge Technical Task Force, funded by the U.S. Minerals Management Service, and managed by DOGAMI. A particularly significant result of the *Sea Cliff* dives was the discovery, at the northern end of the ridge, of an active hydrothermal vent field, named the Sea Cliff Hydrothermal Field.

*Sea Cliff diving and sediment studies on the Gorda Ridge*, by R. Karlin, Mackay School of Mines, University of Nevada-Reno. A study concentrating on the possible relations between hydrothermal activity and metamorphism of the hosting sediments. Open-File Report O-89-04, 17 p., \$5.

*Soft-sediment hydrothermal vent communities of Escanaba Trough: Comparison with other vent and non-vent communities from similar depths in the deep sea and the influence of chemosynthetic production on the surrounding deep-sea benthic community*, by J.F. Grassle and C.L. Van Dover, Woods Hole Oceanographic Institution. Description and discussion of biological and chemical data obtained during dives of both submersibles. Open-File Report O-89-05, 25 p., \$5.

*Biological results from DSV Sea Cliff exploration of the northern Gorda Ridge*, by G.L. Taghon, College of Oceanography, Oregon State University. Description of biological communities of the Sea Cliff Hydrothermal Field. Open-File Report O-89-06, 4 p., \$4.

*Studies of hydrothermal effluents on the Gorda Ridge*, by R.W. Collier, College of Oceanography, Oregon State University. Analyses of data from earlier dives, used in this report to develop the location of survey sites and dive targets as well as sampling equipment and strategies for the *Sea Cliff* dives. Open-File Report O-89-07, 13 p., \$5.

*Submersible observations and bottom-sample analyses of the Sea Cliff Hydrothermal Field, Gorda Ridge*, by J.S. McClain and P. Schiffman, Department of Geology, University of California at Davis. Geologic study indicating the importance of the rift valley wall faults for hydrothermal circulation. The authors emphasize that future exploration for minerals should include work on the walls as well as the center of the rift valley. Open-File Report O-89-08, 27 p., \$5.

All five reports are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. Orders under \$50 require prepayment. □

## DOGAMI honors mining operators



*Bay View Transit operation at Squaw Creek near Seaside, Oregon, honored with the Outstanding Operator Award.*

On March 23, 1989, the Oregon Department of Geology and Mineral Industries (DOGAMI) presented its Outstanding Operator Award to Bayview Transit Mix, Inc., of Seaside and its Reclamation Project Award to Central Oregon Pumice Company of Bend.

Honorable mention for the awards went to Bracelin-Yeager Excavating and Trucking, Inc., of Coos Bay; Ohbayashi Corporation of San Francisco; Beaver State Sand and Gravel, Inc., of Roseburg; and Bend Aggregate and Paving Company of Tumalo.

The Operator Award recognizes operational design and conduct that lead to exceptional environmental protection. The Reclamation Award honors reclamation projects that exemplify the goals of the reclamation statutes of the state.

The award winners were chosen by a selection committee composed of representatives from the mining industry, the legislature, and environmental interest groups. DOGAMI's Mined Land Reclamation Program staff assisted in coordinating the award program.

The Outstanding Operator Award to Bayview Transit Mix, Inc., honored the company's initial development of a hard-rock quarry operation in Clatsop County near the Seaside-Cannon Beach highway interchange, on property owned by Cavenham Forest Industries.

Previous use of this property had been for timber production. A small hillside excavation had served the landowner's need of rock for log-hauling roads. The newly developed quarry, which ultimately will encompass 20 acres, is removed from public view by a private access road several miles long.



*Bayview Transit settling pond with overflow system used to irrigate hillside vegetation.*



*Central Oregon Pumice reclaimed mining area near Bend, Oregon, honored with the Reclamation Project Award.*

After Clatsop County granted zoning approval, the operator received the permit for a commercial quarry site and began site development in August 1988. The soil removed from the natural 1:1 slope was deposited at the toe of the excavation face in what is known as a "compacted fill" (deposition by layers, each layer compacted by rollers before the next layer is started). The compacted fill was covered with crushed rock, its surface was sloped for drainage, and the area was developed as site for a crusher plant and stockpile.

Immediately downslope from the plant site, a sedimentation pond was excavated. A berm around the plant site will now direct surface-water runoff into the sedimentation pond. From the pond, the overflow will feed a trickle-irrigation system spread across the hillside, which is covered with a 10-year-old stand of Douglas fir and hemlock. Thus, the waste-water discharge is effectively separated from a Class I perennial stream nearby.

In October 1988, all slopes, banks, and other areas where bare soil was exposed were seeded with a mixture of several grasses and clover, and an organic mulch tackifier was applied.

Central Oregon Pumice was honored for its reclamation of mining claims identified as Devil's Flat 1 and 3. The 24-acre parcel of



*Central Oregon Pumice mining claim (same view as previous photo), while in operation. Subsequent recontouring and revegetating during reclamation have led to the reestablishment of productive, self-sustaining systems.*



land had been wholly disturbed by mining prior to 1972. Thus, the site was exempt from the Oregon Mined Land Reclamation Act, and the reclamation that was completed there was voluntary under state law.

By developing improvements in its operation, Central Oregon Pumice had been able to reenter this older mine area in the early 1980's and continue commercial production of pumice that had not been usable before because of its high moisture content. This production was then combined with reclamation.

The reclamation began with backfilling the 50-ft-deep excavation with volcanic ash. Before the final recontouring, the area was left idle for one year to allow for differential settling of the backfill. In the spring of 1986, the reclaimed area was seeded with crested wheatgrass and a pasture mix, and weedy species, primarily woolly mullein, were removed by hand.

Central Oregon Pumice reports that the reclaimed area shows the same degree of intensive deer usage as other reclaimed areas in the vicinity. Up to 50 deer at a time have been observed on this 24-acre parcel. The reclaimed grassy areas provide open spots that are favored by grazing wildlife. The surrounding vegetation is denser, consisting of lodgepole and Ponderosa pine with an understory of bitterbrush, rabbitbrush, and sagebrush.

Because of the date of the original disturbance of the area, this reclamation effort was completed without topsoil replacement. The topsoil is now salvaged and stockpiled separately for reclamation on the new mine areas. □

## Earthquake hazards workshop successfully completed

The Oregon Department of Geology and Mineral Industries was pleased to host the National Earthquake Hazard Reduction Program's 1989 Workshop on Earthquake Hazards in the Portland/Puget Sound Areas in Portland during the last week in March. The workshop was sponsored jointly by the U.S. Geological Survey (USGS), Federal Emergency Management Agency (FEMA), Oregon Emergency Management Department (EMD), Washington Department of Emergency Management (DEM), and Washington Department of Natural Resources (DNR). The purpose of the workshop was to bring together geoscientists, engineers, planners, emergency managers, businessmen, insurers, and local government officials to discuss the rapidly evolving changes in the understanding of earthquake hazards in the region.

Over 200 participants were involved in two days of presentations and discussions and a well-attended poster session. John Nance, popular author of *On Shaky Ground*, a book about earthquake hazards in America, presented a luncheon address. Finally, 60 participants went on a rainy field trip to the Oregon coast where they viewed evidence for past great earthquakes—and discovered new evidence in the process!

Although much attention was focused on the possibility of "the big one," a megathrust earthquake on the Cascadia subduction zone, participants also discussed the much better defined hazards from known seismic zones in the Puget Sound and in Portland. They generally agreed that the hazard was greater than had been previously considered and that both metropolitan areas are very poorly prepared for earthquakes. Rob Wesson, chief of the USGS Office of Volcanoes, Earthquakes, and Engineering, talked about the increased understanding of earthquake hazards in the area and summarized by saying, "The news is not good." Wesson stated that "If the earthquake that is argued to be possibly associated with this subduction zone is indeed realistic, then the earthquake hazard in Portland due to the Cascadia subduction zone is comparable to the earthquake hazard in Los Angeles due to the San Andreas Fault."

—Ian Madin, Oregon Department of  
Geology and Mineral Industries

## OIL AND GAS NEWS

### ARCO drills Clatsop County wildcat

During March, ARCO drilled the Oregon 21-33-86 well, located in sec. 33, T. 8 N., R. 6 W., about 10 mi northwest of the Mist Gas Field. The well was drilled to a total depth of 5,895 ft and was abandoned as a dry hole. No details have been released on the well.

### Two-state task force on OCS leasing formed

A task force has been formed to advise the Secretary of the Interior on issues related to potential outer continental shelf (OCS) oil and gas leasing. The Pacific Northwest Outer Continental Shelf Task Force consists of J. Lisle Reid (Minerals Management Service), David McCraney (State of Washington), Gail Achterman (State of Oregon), James Harp (Northwest Indian Fisheries Commission), and Gordon HighEagle (Columbia Intertribal Fish Commission). The task force met for the first time on March 27, 1989.

The initial task will be to assist in the development of the environmental studies program for the Washington-Oregon OCS region. The Minerals Management Service, which conducts environmental studies for all OCS regions, will work with the task force in planning and implementing the studies. The task force will recommend areas to be deferred from the 1992 lease sale (if held) and will specify which environmental studies should be completed before a Draft Environmental Impact Statement is issued.

### Correction on NWPA symposium announcement

The 1989 spring field symposium of the Northwest Petroleum Association (NWPA) will be held May 18-19, in **Leavenworth**, Washington (not Spokane, as erroneously announced at this place in the January issue). Contact person for additional information is Phil Brogan, 1426 NW Harmon Blvd., Bend, Oregon 97701; phone (503) 382-0560.

### Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
420	ARCO Columbia Co. 34-28-65 36-009-00249	SW ¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Application; 1,930.
421	ARCO Columbia Co. 42-32-74 36-009-00250	NE ¼ sec. 32 T. 7 N., R. 4 W. Columbia County	Application; 1,750.
422	ARCO CER 24-18-64 36-049-00251	SW ¼ sec. 18 T. 7 S., R. 4 W. Morrow County	Application; 1,675.
423	ARCO CER 41-16-64 36-009-00252	NE ¼ sec. 16 T. 6 N., R. 4 W. Columbia County	Application; 2,375.
424	ARCO Hamlin 33-17-65 36-009-00253	SE ¼ sec. 17 T. 6 N., R. 5 W. Columbia County	Application; 2,980.
425	ARCO CER 23-22-64 36-009-00254	SW ¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Application; 1,330. □

## ABSTRACT

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

**STRATIGRAPHIC AND GEOCHEMICAL EVOLUTION OF THE GLASS BUTTES COMPLEX, OREGON**, by Richard L. Roche (M.S., Portland State University, 1987), 99 p.

The Glass Buttes complex lies at the northern margin of the Basin and Range Province in central Oregon and is cut by the northwest-trending Brothers fault zone. An older acrySTALLINE volcanic sequence of high-silica rhyolites (> 75 percent SiO<sub>2</sub>) forms a broad platform composed of domes and flows with minor pyroclastic deposits. The high-silica rhyolite sequence is divided on the basis of texture into (1) zoned flows and domes, (2) obsidian flows, (3) felsite flows, and (4) biotite-phyric flows and domes. Stratigraphic relations indicate that high-silica rhyolite units in the western part of the complex overlie those to the east. K-Ar age determinations for the sequence range from 5.03 to 7.7 m.y. Geochemical trends within the sequence are characteristic of highly evolved magmas. The majority of the elements analyzed within the Glass Buttes high-silica rhyolite sequence fall into two groups that display similar behavior: (1) Sc, Rb, Cs, Sm, Tb, Yb, Lu, Ta, Th, U, and (2) Mg, Ca, Ti, Fe, Co, Ba, La, Ce, Nd, Eu, P. Elements within each group generally show positive correlations with each other, but negative correlations with elements of the other group. The variations between the two groups reflect the chemical stratification present within the high-silica rhyolite magma chamber prior to the eruption of the sequence. The presence of biotite phenocrysts within the sequence may indicate that the high-silica rhyolites were erupted from a relatively shallow magma chamber.

The vent locations of a younger volcanic sequence of rhyolites and rhyodacites are strongly controlled by structure. Vents are aligned along the trend of the Brothers fault zone. The petrology and geochemistry of the sequence indicate that it is not genetically related to the high-silica rhyolite sequence of volcanism. The rocks are phyric and contain various proportions of plagioclase (andesine-labradorite), hornblende, quartz, biotite, and ortho- and clinopyroxene phenocrysts. Phenocrysts range up to 40 percent of the rock volume. There are large variations in the concentrations of Fe, Mg, Ca, Ti, Sc, Co, Cr, and Eu among the different rhyolite and rhyodacite flows, indicating that the different flows represent distinct, but genetically related, magma batches.

Basaltic volcanism occurred throughout the silicic eruptive sequence. Several of the basalt flows erupted within the Glass Buttes complex show petrographic and geochemical evidence of contamination by rocks of the high-silica rhyolite sequence. The intrusion of basaltic magma into the crust is believed to have provided the heat source for the partial melting of crustal materials, leading to the generation of the silicic magmas. □

## Mineralogical Symposium features zeolites

The Pacific Northwest chapter of the Friends of Mineralogy will hold its 15th Annual Mineralogical Symposium from Friday, September 29, through Sunday, October 1, 1989, at the Executive Motor Inn in Tacoma, Washington. Featured subject of the symposium will be zeolites.

The three-day program will present approximately a dozen speakers who will discuss zeolites under a variety of aspects, including the formal presentation of two new zeolites.

The symposium program will also include a banquet dinner, a benefit auction as part of the Saturday evening program, micromount tables and trading sessions, and competitions for the best photos and slides and the best self-collected minerals.

In addition to displays of the Friends of Mineralogy, five major dealers from the United States and Canada will have displays on the show floor, and several dozen satellite dealers will be located in guest rooms of the Executive Inn. Displays and dealer shows will be open to the public Friday and Saturday evenings with an admission charge of \$2.

More information on registration and program is available through John Lindell, 3311 NW 74th, Seattle, WA 98117. Satellite-dealer information may be obtained from Ray Lasmanis, #155, 910 Sleater Kinney SE, Lacey, WA 98503.

—*Friends of Mineralogy announcement*

## NWPA holds symposium

The Northwest Petroleum Association (NWPA) will hold its fifth annual symposium at Leavenworth, Washington, on May 18-20, 1989. The hydrocarbon potential of the Columbia Basin, Oregon and Washington, will be addressed with emphasis on potentially productive Eocene and Oligocene sediments underlying the Columbia River basalts. The symposium schedule includes one day of technical-paper presentation and two days of field trips in the Chiwaukum graben and the Roslyn "basin."

Additional information is available from Phil Brogan, 1426 NW Harmon Blvd., Bend, Oregon 97701, phone (503) 382-0560.

—*NWPA news release*

## GRC announces annual meeting

The Geothermal Resources Council (GRC) will hold its 1989 Annual Meeting October 1-4 at the El Rancho Tropicana Hotel in Santa Rosa, California, and has issued a call for papers for this meeting.

Santa Rosa is the closest major city to The Geysers. The geothermal field is celebrating its third decade of operation, and the emphasis of the meeting will therefore be on the technological development, production history, and regulatory and environmental issues that have evolved from this activity.

For the first time, a trade show will be held in conjunction with the meeting. It will be developed and managed by the National Geothermal Association and will consist of the usual indoor exhibits and an outdoor Tech Yard.

Field trips will concentrate on The Geysers Geothermal Field and cover at least six different subjects on separate trips. On the subject of geothermal direct use, a special one-day field trip has been scheduled to Calistoga in the Napa Valley and to a geothermal-greenhouse project in Lake County.

Papers are solicited in the following areas:

- Exploration—geology, geophysics, geochemistry, and hydrology
- Drilling and well design—shallow and deep
- Field development—civil and geologic engineering
- Production technology—pipe lines and production facilities
- Reservoir engineering—production-well testing, injection, and modeling
- Power generation and plant operation—small and large, low- and high-temperature, construction and power transmission
- Legal and institutional aspects
- Economics, financing, and marketing
- Environmental aspects
- Direct use—agri- and aquaculture, manufacturing, and space heating

(Continued on page 70, GRC)

# Reclamation of exploratory drill sites in Oregon

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

## INTRODUCTION

Reclamation refers to the restoration of a drill site to a condition that is of beneficial use to the surface owner. By definition, reclamation of a surface operation means the use of procedures reasonably designed to minimize as much as is practical the disruption from the surface operation and to provide for the rehabilitation of any surface resources adversely affected by such surface operations through rehabilitation of plant cover, soil stability, water resources, and other measures appropriate to the subsequent beneficial use of such reclaimed lands. In any oil and gas exploratory drilling operation that is done in Oregon, the Oregon Department of Geology and Mineral Industries (DOGAMI) has regulatory authority to ensure that reclamation of a drill site is done in a manner deemed acceptable to both this agency and to the surface owner.



Figure 1. A typical drill site in Oregon involves about 1 acre of land. This is the OGD well IW 33c-3 at Mist Gas Field drilled during 1987.

## EXPLORATORY DRILL SITES: IMPACT

When an oil or gas well is proposed in Oregon, an operator submits an application that includes a plan of operation to DOGAMI. When this applicant receives a permit to drill, the existing reclamation requirements by the State of Oregon are required to be followed. Part of the application requirement is for the operator to post a \$25,000 individual well bond or \$150,000 blanket bond. This bond will not be released until all operations, including reclamation, are concluded in a satisfactory manner.

In general, a drill site in Oregon disturbs about 1 acre of land and is rectangular in shape (Figure 1). It is graded flat, with a sump on one side. The drilling operation itself usually takes about two weeks or less, at which time the drill site is reclaimed, should the well be a dry hole. If the well is successful in finding oil and gas, the site remains in use for the lifetime of the well. In either case, the drilling and production use of a site are temporary, after which the site is reclaimed.

## RECLAMATION OF DRILL SITES

In Oregon, oil and gas drilling operations have been primarily in the Mist Gas Field area since its discovery in 1979. The field is located in Columbia County and is in a forest area. The drilling operations have proved to be compatible with the forest use operations. The timber companies have benefited economically by receiving royalty payments from gas production on their lands and have found the drill sites to be useful in their forest harvest operations. This compatible balance of gas drilling and forest use has influenced the reclamation decisions of drill sites at Mist Gas Field. In most cases, when a well is abandoned, the drill site is returned to its original forest condition for replanting (Figure 2). If the site had gravel placed on it during construction, the gravel is scraped and removed for use on roads, and the top soil is replaced before replanting.

In some cases, where the drill sites are located in areas of old trees scheduled for future cutting, the site is left for use as a landing during tree harvesting. It will then be replanted upon completion of the cutting operations. This reclamation method fits well with forest use planning in that drilling operations and forest operations coexist in a compatible relationship. Compatibility of drilling and surrounding land use exists at the Mist Gas Field and other locations throughout Oregon, including areas of agricultural use.



Figure 2. This reclaimed drill site is for the Leadco well CC-Jackson 22-17 at Mist Gas Field. This abandoned well was drilled on Cavenham Forest Industry land during August 1987.

## SUMMARY

Reclamation of drill sites provides restoration of the affected land to a beneficial use. In Oregon, a drilling operation generally temporarily affects about a 1-acre area. Subsequent reclamation required of the operator must be acceptable to both DOGAMI and the surface owner. In forest use areas, such as Mist Gas Field in Columbia County, the drilling operations have proved to be compatible with forest operations. Drill sites are replanted for forest use, unless the owner desires to use the site as a landing during tree cutting operations, after which it will be replanted. Compatibility of drilling operations and surrounding land use also exists in agricultural use areas. □

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## BOOK REVIEW

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by Paul F. Lawson, mineral collector and retired Supervisor, Oregon Department of Geology and Mineral Industries, Mined Land Reclamation Program

**Crystals and Minerals: A Family Field Collecting Guide for Northwestern Oregon and Southwestern Washington**, by Jon Gladwell, 1989. Price \$7.95. 43 pages, 5½ by 8½ inches. Available from the author at 2018 East Sixth Street, Vancouver, Washington 98663.

This well-organized guidebook to sixteen sites in the subject area has a number of outstanding features. All mineral-collecting guides should have these features, but unfortunately few do to an equal degree. I am referring to the author's discussion of tools and equipment, his rating of ease of access to sites, and recommended equipment for each site. Also, he tells the reader what minerals can be expected at each site and by his line drawings shows the newcomer what to look for. A trip log, an individual site map, and references to the appropriate U.S. Geological Survey quadrangle maps are provided for each site. The author also provides a brief resume of each site and conditions attendant to it. Commendably, he summarizes safety considerations for each site where appropriate. It would have been desirable to mention that poison oak is abundant (and very virulent to some persons) in timber or brush in the Kalama area and in the Columbia River Gorge. Additionally, at points east of Beacon Rock, scorpions are numerous but not usually aggressive.

As in most guides, a few areas in this one should have a second look. For example, at the Kalama site, page 12, unless the Washington State Police have changed their attitude, you are likely to get a warning or a citation if you are collecting within the right-of-way along Interstate I-5. Their rationale seems to be that any activity on the right-of-way is a distraction to motorists.

By reference to the distance to Kelley Creek, page 34, the author appears to suggest that Kelley Creek is not an appropriate name for the gismondine location. If this is the case, and since the Kelley Creek name almost certainly has no official status in relation to this site, why perpetuate it in print? More importantly, the author refers to abundant gismondine at the road level, when, unless there have been recent additional finds, the supply of gismondine at the road level appears to have been about exhausted.

For the Boulder Creek site, page 36, the author indicates a specific copy of the *Ore Bin* for directions, then provides a log of the area for those collectors who do not have the *Ore Bin*. If the collector does not have the *Ore Bin*, how does he or she get to checkpoint 00.00?

Few of the sites listed are new to collectors who have been active in the area for several years. The book does not include some sites it might. On the other hand, few, or perhaps none, of these sites have been located or described as well in any field guide to date. This guide should be useful to the family, as targeted, to beginning collectors, and to collectors new to the area. Whether the value of this guide justifies its price is a decision each prospective purchaser must make for himself or herself. □

## AASG publishes history of State Surveys

The Association of American State Geologists (AASG) has recently published *The State Geological Surveys—A History*, a compilation of the histories of state geological surveys in the United States.

Edited by retired Pennsylvania State Geologist Arthur A. Socolow, the illustrated, hard-covered, 499-page book contains descriptions of the history, organization, and functions of the 50 State Geological

Surveys. Each state is represented in an individual chapter prepared by the respective Survey.

This comprehensive volume was produced in recognition of the major role the State Geological Surveys have played in geologic mapping and research accomplished in the United States over the past 150 years. Diverse in name, size, and detailed functions, the 50 State Surveys, of which more than 30 originated over 100 years ago, have the basic responsibility to delineate the geologic framework and the geologic resources of their states.

*The State Geological Surveys—A History* may be ordered from the Geological Survey of Alabama, P.O. Box 0, Tuscaloosa, AL 35486. The price is \$20 and includes shipping. Checks are to be made payable to the AASG.

—From AASG news releases

## USBM issues state-by-state report on mineral production

The U.S. Bureau of Mines (USBM) has released a report on non-fuel mineral production in 1988. The new 187-page book, *State Mineral Summaries 1989*, is the earliest government publication to furnish estimates covering annual nonfuel mineral production in each of the 50 states. It is also the first USBM release of the state mineral summaries in one volume and is offered in addition to the usual, separately printed, individual state summaries.

Nonfuel minerals include all minerals except coal, petroleum, and uranium. The reported figures are preliminary estimates, usually based on the data from nine months. Final mineral-production information will be published at a later date in the *USBM 1988 Minerals Yearbook*.

According to the preliminary statistics for 1988, California led the nation in nonfuel mineral production for the fifth year in a row, recovering minerals worth an estimated \$2.85 billion, a 12-percent increase over 1987. Principal minerals in California were cement, sand and gravel, and boron. Only second-ranked Arizona produced a similar value, \$2.83 billion, mainly with copper, sand and gravel, and cement. Oregon ranks 39th with an estimated production value of \$169 million, principally from crushed stone, sand and gravel, and cement.

In the new volume, the summaries have been expanded to provide more information on mineral activities in every state. Each summary includes sections on such matters as employment, exploration, environmental issues, government legislation and programs, and a review of each mineral produced in the state.

The new document is designed to be a companion volume to another USBM document, *Mineral Commodity Summaries 1989*, a preliminary report, by commodity, on the production of 82 nonfuel minerals during the previous year.

Single copies of both preliminary reports may be obtained without charge from the Publications Distribution Section, U.S. Bureau of Mines, Cochran Mill Road, P.O. Box 18070, Pittsburgh, PA 15236; phone (412) 892-4338.

—USBM news release

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(GRC, continued from page 68)

All papers will be considered for publication in the *Transactions*; approximately 70 will be selected for oral presentation and approximately 30 for presentation in the poster session. Final deadline for submission is June 9, 1989. Papers must be delivered to the Geothermal Resources Council, 2121 Second Street, Suite 101A, Davis, California, phone (916) 758-2360, or mailed to P.O. Box 1350, Davis, CA 95617-1350; Telex 882410; Fax (916) 758-2839.

For the annual photography contest, submission deadline is September 1, 1989. Chairman and contact person is Nic Nickels, Eastman Christensen, 3636 Airway Place, Santa Rosa, CA 95403; phone (707) 523-1751.

—From GRC announcement



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VOLUME 51, NUMBER 4

JULY 1989



**SMITH ROCK AND THE GRAY BUTTE COMPLEX**  
*Also in this issue:*  
**COLLECTING FOSSILS — COLLECTING THUNDEREGGS**  
**EARTHQUAKE HAZARD ASSESSMENT IN OREGON**

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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 DOGAMI.

## COVER PHOTO

Large-scale soft-sediment flexure preserved in bedded Smith Rock tuff (unit Tgs) along the ridge crest east of Smith Rock State Park. Unconsolidated tuff probably slumped or flowed slightly downslope, "wrinkling" the bedding. Article beginning on next page discusses geology of this central Oregon area.

# OIL AND GAS NEWS

## DOGAMI conducting rule review

The Oregon Department of Geology and Mineral Industries (DOGAMI) is conducting a tri-annual review of oil and gas rules under Chapter 632, Division 10. No changes are proposed, and written comments are solicited by the agency for review.

## NWPA holds symposium and elects new officers

The Northwest Petroleum Association (NWPA) held its annual spring symposium in Leavenworth, Washington, during May. The geology of the Columbia River basin was discussed in both talks and field trips. Officers for the NWPA elected for 1989-90 are Dennis Olmstead, president; Barbara Portwood, vice-president; Nancy Ketrenos, secretary; and Todd Thomas, treasurer.

## Ocean planning task force sets draft policy

The Oregon Ocean Resources Management Task Force met during May in Lincoln City. The Task Force has decided on an initial draft policy that prohibits oil and gas exploration and development in Oregon territorial waters. Research for the public domain would be allowed.

## Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
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428	DY Oil Forest Cav 13-6 36-009-00257	SW 1/4 sec. 6 T. 5 N., R. 5 W. Columbia County	Application; 2,000.
429	DY Oil Burris CC 24-8 36-009-00258	SW 1/4 sec. 8 T. 5 N., R. 4 W. Columbia County	Application; 3,000.
430	DY Oil Lane CC 24-5 36-009-00259	SW 1/4 sec. 5 T. 5 N., R. 5 W. Columbia County	Application; 2,000. <input type="checkbox"/>

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# Smith Rock and the Gray Butte complex

by Ellen Morris Bishop, Department of Geology, Oregon State University, Corvallis, Oregon 97331\*

## INTRODUCTION

There are plenty of places in Oregon where the scope of the earth and the puniness of man can be witnessed with resounding impact. Few of them are more abrupt in their message than Smith Rock and the adjacent gorge of the Crooked River.

From the beaver-hewn stumps on the torrent's bank, sheer walls tower 300 ft above a river hastening the Ochoco Mountains' winter to the sea. The vertical cliffs rise luminous, rosy and inviting in the morning light, yet stern and coldly foreboding in the late afternoon: mute, pale magenta parapets of challenging stone. The rolling growl of the water, a whisper of wind, and an echoing sense of remoteness from the frenetic outside world give us each a private interlude with forces monstrously and magnificently larger than ourselves.

But what built these ramparts? How long have they stood? And what bricks, what mortar bind them?

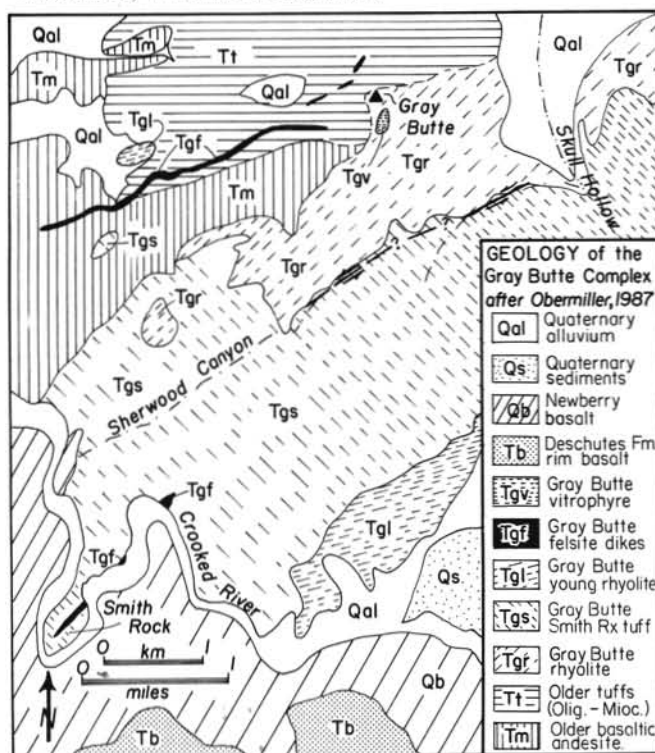


Figure 1. Generalized geologic map of the Gray Butte complex, including the Smith Rock area (after Obermiller, 1987).

Smith Rock is part of a larger eruptive center, the Gray Butte complex, that includes Gray Butte, Coyote Butte, Skull Hollow, and Sherwood Canyon. Its history is long and complicated, its details are still obscure, and its relatives and parents largely unheralded. But geologists are gaining in understanding of these spectacular outcrops.

Smith Rock and the rest of the Gray Butte complex, along with other silica-rich central Oregon eruptive centers including Cline Buttes and Powell Buttes, are located near the western end of the Brothers Fault Zone that bounds the northern edge of the Basin and

Range province (Lawrence, 1976). These centers sit in a structural depression between the Blue Mountains old, accreted arc terrane and the Western and High Cascades volcanic arc.

To understand the geology of Smith Rock, the entire Gray Butte complex must be examined in more detail. The five igneous units that compose most of the Gray Butte complex, including Smith Rock, are identified by the name "Gray Butte" on the area geologic map shown in Figure 1. The Gray Butte units range in lithology from coarse olivine basalts and basaltic andesite to rhyolite and pyroclastic units. Work by Obermiller (1987) indicates that the complex is Miocene in age, erupted between 18 and 10 million years (m.y.) ago, which means that Smith Rock is younger than many geologists had previously thought.

## BASEMENT OF THE GRAY BUTTE COMPLEX

To the north of the Gray Butte complex, Haystack Butte and Juniper Butte are composed in part of Eocene rocks of the Clarno Formation, mostly 40 to 48 m.y. in age. These rocks are mostly basalt and andesite flows and a few domes of more silica-rich composition. The Clarno Formation, which is intermittently exposed between the towns of Warm Springs, Prineville, Mitchell, and Fossil, is similar in lithology and chemistry to Cascade rocks. These rocks are calc-alkaline basalts and andesites of convergent margins, with mudflows and lahars suggesting the presence of at least a few stratovolcanoes.

Overlying the Clarno-age rocks at Haystack Butte, Juniper Butte, and as far east as the Painted Hills and the John Day valley are tuffs, rhyolites, and olivine basalts of the John Day Formation of Oligocene and early Miocene age. Ash found in this unit, which ranges in age from 37 to 19 m.y., probably came from volcanic vents in the vicinity of the Cascades (Robinson and others, 1984).

## THE CLARNO AND JOHN DAY FORMATIONS AT GRAY BUTTE

The Gray Butte complex has previously been correlated with the John Day Formation on the basis of silicic lithologies and the presence of fossil leaves (Robinson, 1975). These rocks are exposed from Haystack and Juniper Buttes southward to Gray Butte.

According to Obermiller (1987), however, older rocks occur on the northern buttress of the Gray Butte complex. They consist of poorly exposed conglomerates and tuffs overlain by altered basalts and basaltic andesites, most probably of Clarno age. The area north



Figure 2. Flow banding in the Gray Butte rhyolite (unit Tgv in the geologic map shown in Figure 1). Photo field is approximately 8 in. across.

\*Ellen Bishop has collected several of her *Time Travel* columns about the mountains of Oregon that appeared in the *Oregonian* and has published them in a spiral-bound book called *Tales the Mountains Told*. The book is sold in several central Oregon bookstores for \$5.95. It is also available from her directly at Route 1, Box 248, Terrebonne, OR 97760, for \$7 postpaid.



Figure 3. Rhyolite dike (unit Tgf) west of Gray Butte. View is to the east, and Gray Butte is in the background. Note horizontal columnar jointing in dike.

of Gray Butte also contains small patches of an ash-flow tuff and other rhyolite tuffs of the John Day Formation. Tuffs of probable early Miocene age are also present (Obermiller, 1987).

## LITHOLOGIES OF THE GRAY BUTTE COMPLEX

### Introduction

The rocks of the Gray Butte complex overlie and intrude the Eocene to Oligocene sequence. They are dominantly silica-rich.

### Older rocks

Andesite flows apparently representing the earliest eruptive products of the Gray Butte complex occur as a relatively fresh basaltic andesite dated at 18.9 m.y. (K-Ar whole-rock) forming a broad apron north of Gray Butte (Obermiller, 1987).

The tuffaceous beds in these units largely appear to have been deposited in shallow water and contain a variety of plant fossils in-

dicating that the climate, which was subtropical during the Eocene, gradually became more temperate (Ashwill, 1983; McFadden, 1986).

Geologists are unsure whether these rocks of early Miocene age are related to the same eruptive events that created Gray Butte and Smith Rock.

### Gray Butte rhyolite

According to Obermiller's (1987) work, the earliest silicic unit of the Gray Butte complex is the Gray Butte rhyolite (Figure 2). This thick accumulation of flow-banded rhyolite occupies the northern portion of Gray Butte and is well exposed in Sherwood Canyon. It overlies tuffs of uncertain age that may be related to the Gray Butte complex. Its potassium-argon (K-Ar) whole-rock age is 17.8 m.y. The rocks show considerable flow folding, and a thin, glassy layer is present at the base of the unit. The absence of primary flow features such as lithophysae and spherulites and the presence of abundant axiolites and plastically deformed glass shards suggest that the Gray Butte rhyolite is a rheomorphic tuff, which is an ash-flow tuff that flowed after its emplacement (Obermiller, 1987).

The vent location for the Gray Butte rhyolite is not known. Little evidence, such as brecciation or local alteration and domes on Gray Butte itself, is known to indicate a vent location there. Pervasive epithermal alteration west of Gray Butte reported by Gray and Baxter (1986) and Rimal and others (1987) probably postdated eruption of the Gray Butte rhyolite unit. A wide, persistent rhyolite dike (Figure 3) west of Gray Butte may have fed some Gray Butte volcanism.

### Smith Rock tuff

Next oldest unit of the Gray Butte complex is the Smith Rock tuff. It is this tan and red and green unit that forms most of what we think of as Smith Rock and the adjacent ridges, rising in knobs and spires, rhino horns, and broomsticks. It forms the spectacular buff cliffs along the north sides of the Crooked River in Smith Rock State Park, beloved of climbers and those who simply like to feel small (Figure 4). The Smith Rock tuff is a complicated unit consisting of multiple mud and ash flows and pyroclastic deposits.

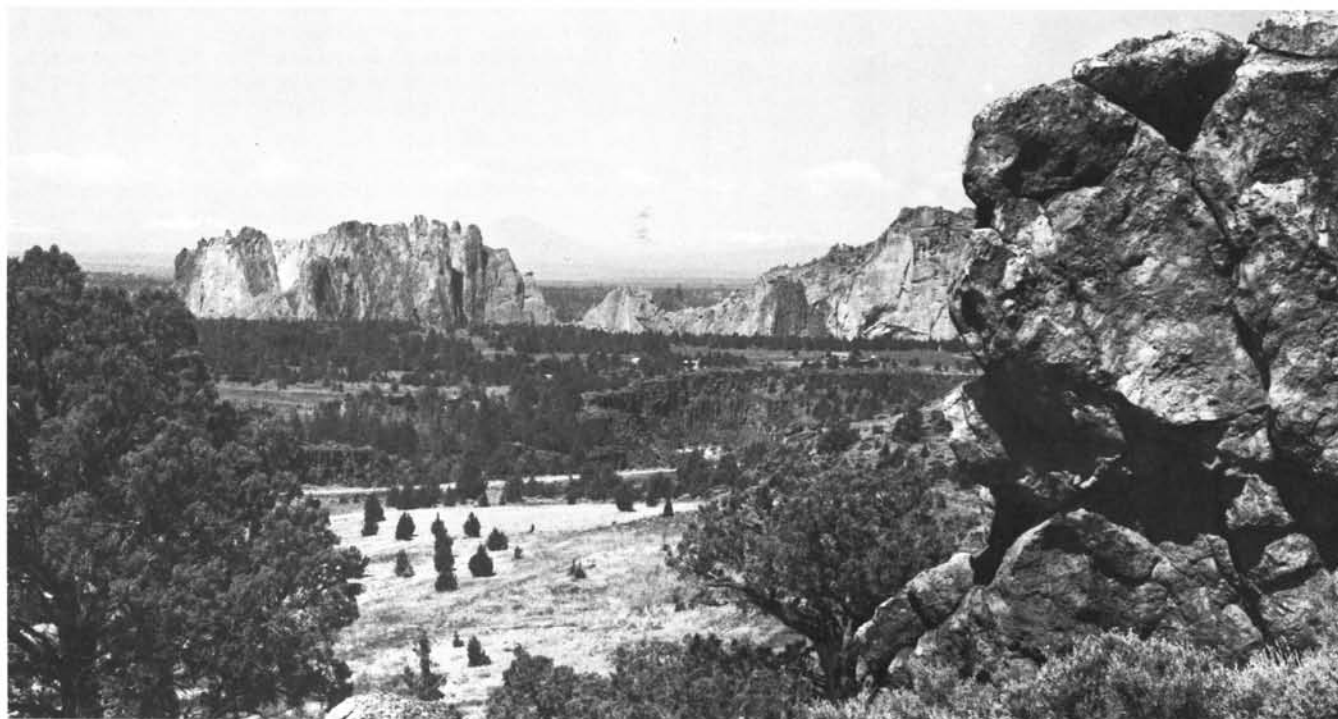


Figure 4. Canyon of the Crooked River winds through Newberry basalts toward Smith Rock State Park. Smith Rock tuff forms most of the high, light-colored cliffs.

The base of the Smith Rock tuff contains clasts of rhyolite and other rocks as well as organic debris including now-silicified tree trunks. Thin rhyolite flows are interbedded with tuffs and mudflows, suggesting that pyroclastic and flow volcanism occurred side by side.

Units of the Smith Rock tuff include mudflows, air-fall tuff, and muddy tuff flows. Angular fragments and autoclasts of rhyolite and tuffaceous material are common, although graded bedding is not, suggesting that material was not transported far and that the source (vent) of the tuffs is near Smith Rock itself (Figure 5). The Smith Rock tuff is bedded and, in some places, shows clear evidence of soft-sediment deformation in the form of soft-sediment folding (cover photo). All of the tuff is devitrified—the glassy ash and pumice fragments and some glassy matrix have been transformed by time and water into clay minerals.

The thickest part of the Smith Rock tuff is located about half a mile west of Smith Rock State Park. The thickness and greater level of alteration suggest that the feeder conduit may be buried there (Obermiller, 1987).



Figure 5. Angular clasts of rhyolite and pumice are abundant components of the porous Smith Rock tuff (unit Tgs). Much of the tuff exhibits subtle bedding. Dips are probably a primary feature of the tuff, indicating initial deposition on the steep slopes of a tuff cone (Obermiller, 1987).

#### The Smith Rock tuff cone

Smith Rock itself may represent part of a tuff cone (Obermiller, 1987)—a low, sloping edifice composed of silica-rich lava that was transformed into hot, fragmental tuffs upon explosive eruption into a wet environment. Tuff cones can be respectable in size: Diamond Head in Hawaii rises as much as 770 ft above the ocean and is more than a mile in diameter. Or they can be small, pocket-sized volcanoes similar to Fort Rock. An as-yet-unanswered question is whether the matrix of Smith Rock was welded together as a hot, sticky, pasty mass immediately after the eruption or was cemented slowly together after deposition. The answer to this question, which requires study with microscopy, will determine whether, technically, Smith Rock is an ash (welded) or tuff (cemented) cone.

#### Other flow rocks of the Gray Butte complex

Several other flows of diverse compositions are present in the Gray Butte complex. A thin, lithophysal rhyolite flow is found in the east-southeast part of the Gray Butte complex, overlying the Smith Rock tuff (Figure 6). It is pink to red and displays good flow banding. This flow is overlain by more mudflow deposits and tuffs so probably is contemporaneous with the Smith Rock tuff.

Thin flows of olivine basalts and basaltic andesites must have been erupted during this time as well. They are exposed on the north side

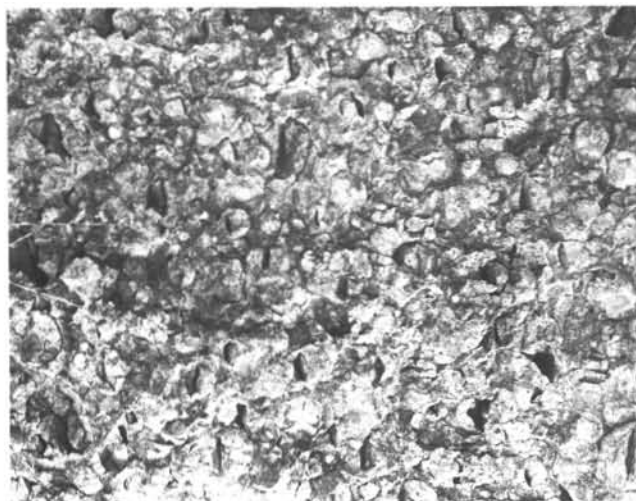


Figure 6. Lithophysae in rhyolite (unit Tgl) east of Smith Rock State Park. These 1- to 2-in. spherical cavities and blisters result from the entrapment of gas (mostly steam and carbon dioxide) within a cooling rhyolite flow. If filled with opal or chalcedony deposited by hot water within the flow, they would be thundereggs.

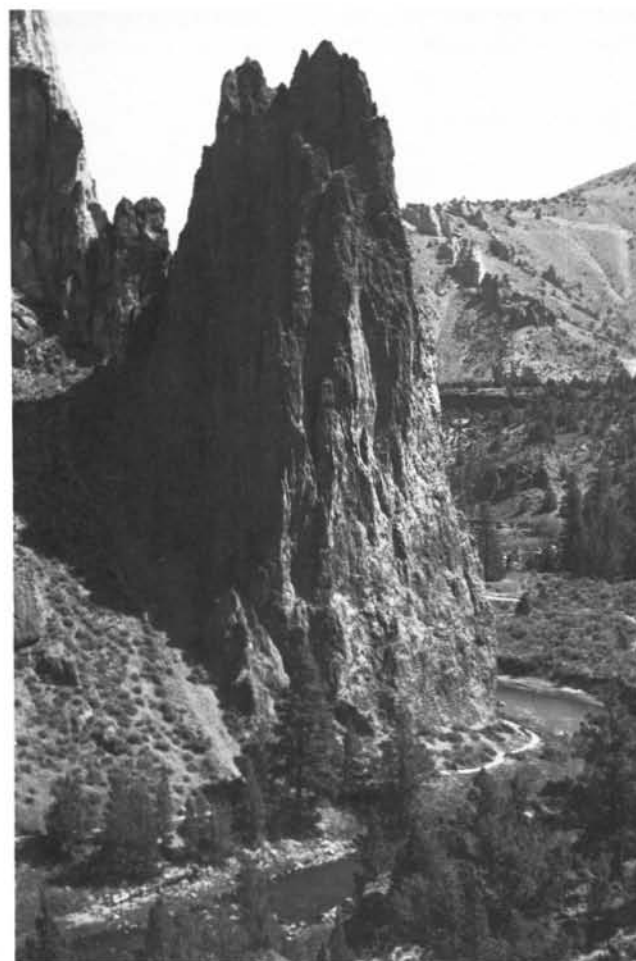


Figure 7. Microfelsite dike (dark rock) (unit Tgf) rises from the Crooked River at Smith Rock State Park. Bench in middle ground is Newberry basalt (unit Qb). Light-colored rocks in background are Smith Rock tuff (unit Tgs).



of the Gray Butte complex along with several basaltic dikes that may have fed the flows. The age obtained for these flows is 17.4 m.y., based upon K-Ar whole-rock measurements (Obermiller, 1987).

#### The Smith Rock microfelsite

Possibly the youngest unit of the Gray Butte complex is a microfelsite dike of rhyolitic composition that forms a distinctive, red, hard, and brittle edifice on the north side of the Crooked River (Figure 7). This narrow, intrusive conduit carried rhyolite magma in near-vertical flow to be erupted somewhere above the present Smith Rock. The microfelsite—seen on fresh surfaces as a light-colored, finely crystalline rock of rhyolitic composition—exhibits good vertical flow banding in some locations and has a chilled margin against the Smith Rock tuff. The dike clearly was emplaced prior to complete solidification and dehydration of the tuff, because less than a foot from the dike, the contact-baked, porcelainlike tuff developed strong vesicularity, as though trapped water had boiled in a cool but unconsolidated country rock. On the west side of Smith Rock, the dike seems mingled with the tuff, suggesting that it intruded in anastomosing, enveloping style, feathering into the surrounding rock.

#### Summit vitrophyre

The youngest dated rock of the Gray Butte complex is a glassy rhyolite, a texture called a "vitrophyre," nestled into the southwest side of Gray Butte's summit. Obermiller (1987) obtained a K-Ar whole-rock age of 10.7 m.y. for this unit. However, its extremely limited extent and its high content of altered glass make this whole-rock age somewhat suspect.

If this date is spurious, then the eruptive history of the Gray Butte complex was brief, perhaps spanning less than 2 m.y.

#### The rimrock basalts

The last volcanic episode written in the rock record exposed along the Crooked River is the eruption of voluminous basalts. They are part of the Deschutes Formation, flowing from the low shield volcanoes to the west—Green Ridge, Squaw Back Ridge, and others—about 4.5 m.y. ago. They lapped up upon a silicic highland—the eroded remnants of the Gray Butte complex, then standing slightly higher than they do at present. The early Crooked River canyon was eroded along the contact. About 1.2 m.y. ago, this canyon was filled by flows from Newberry volcano. These flows form the dark cliffs currently seen along the Crooked River near Smith Rock State Park (Figure 8).

#### PETROLOGY AND GEOCHEMISTRY OF THE GRAY BUTTE COMPLEX

Where did this silica-rich magma come from? How was it generated? For the answers to these questions we must turn to petrology and geochemistry.

According to major-element analyses (Obermiller, 1987), the Miocene basalts associated with Smith Rock are tholeiitic in composition (Table 1). Their content of  $\text{TiO}_2$  (usually >1.5 weight percent) is anomalously high for arc-related volcanics, however, and may be related to their eruption in a back-arc extensional environment east of the Cascades.

Generally, these basalts and basaltic andesites belong to the regime of early island arcs and are chemically distinct from the mid-

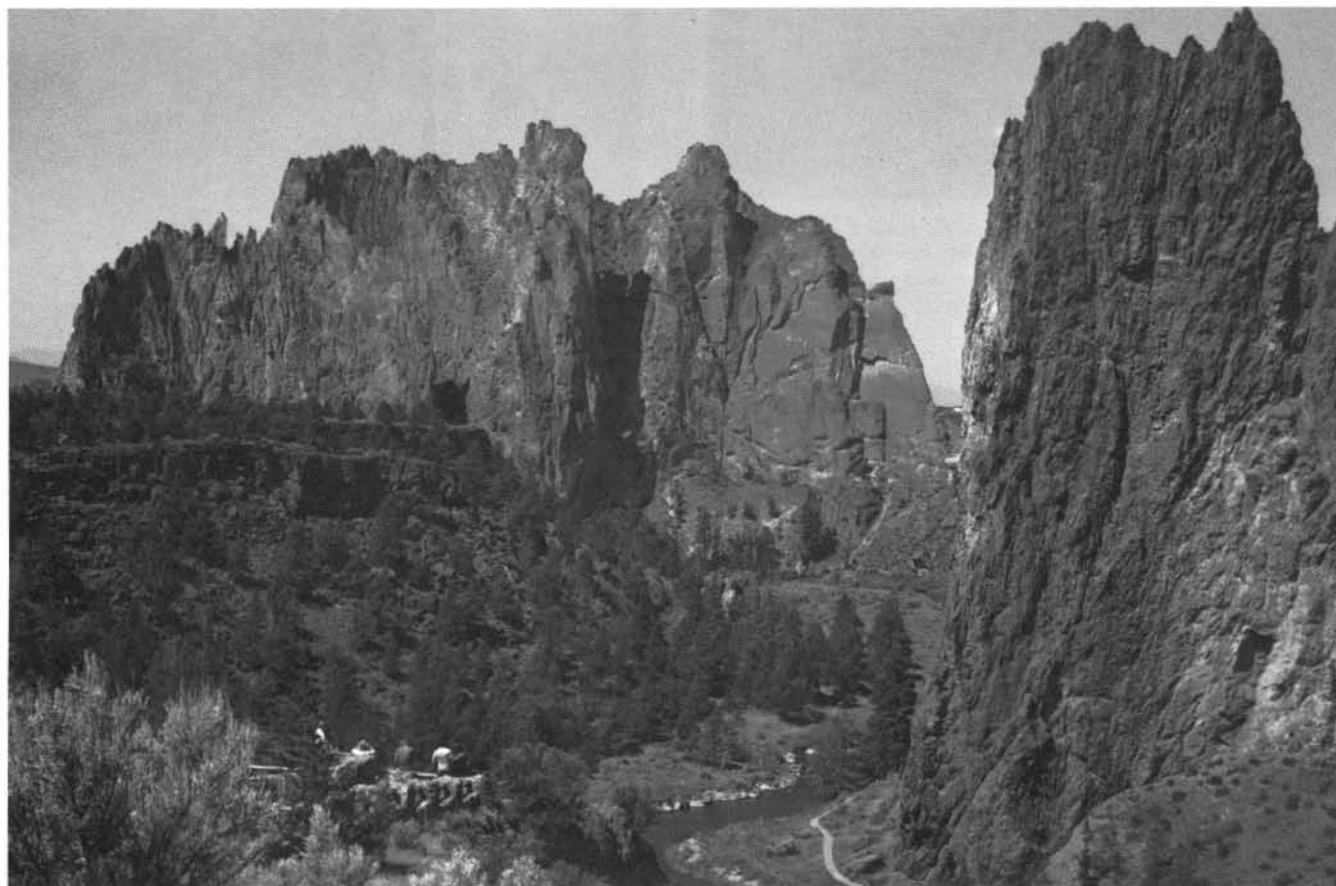


Figure 8. Basalts from Newberry volcano south of Bend flowed down the Crooked River about 1.2 million years ago (Smith, 1986). These intracanyon flows (unit Qb) now form the dark, columned cliffs on the south side of the Crooked River at Smith Rock State Park. Felsite dike (unit Tgf) is exposed at right of photo. Other rocks are predominantly Smith Rock tuff (unit Tgs). View is to the west.



Table 1. Major- and trace-element analyses of rocks from the Gray Butte complex. Data from Obermiller (1987).

Sample no. Rock type	24 Basalt	SR-B-1 Bas. andesite	SR-RH-4 Rhyolite	SR-RH-1 Rhyolite	SR-T-5 Tuff
SiO <sub>2</sub> (wt.%)	50.13	57.86	82.99	77.75	76.36
TiO <sub>2</sub> (wt.%)	2.29	1.79	0.17	0.20	0.28
Al <sub>2</sub> O <sub>3</sub> (wt.%)	15.36	14.58	8.63	12.11	13.36
FeO* (wt.%)	11.65	11.13	1.78	1.35	0.63
MnO (wt.%)	0.20	0.21	0.03	0.01	n.d.**
MgO (wt.%)	6.68	2.63	n.d.**	n.d.**	n.d.**
CaO (wt.%)	9.96	6.41	0.18	0.23	0.13
Na <sub>2</sub> O (wt.%)	2.67	3.86	2.50	4.05	0.82
K <sub>2</sub> O (wt.%)	0.38	0.81	3.75	4.40	8.47
P <sub>2</sub> O <sub>5</sub> (wt.%)	0.63	0.76	0.02	0.02	0.04
Total	99.95	100.04	100.05	100.12	100.09
Ba (ppm)	232	335	658	824	944
Rb (ppm)	28.00	33.40	111	143	342
U (ppm)	n.d.**	n.d.**	3	4	5
Nb (ppm)	17.00	20.00	43	63	59
Zr (ppm)	174	207	349	412	465
<sup>87</sup> Sr/ <sup>86</sup> Sr	0.7042	0.7040	0.7101	0.7096	0.7131
<sup>143</sup> Nd/ <sup>144</sup> Nd	0.51280	0.51295	0.51287	0.51286	0.51289
Age (K-Ar whole-rock in m.y.)	18.9 ± 0.5	17.4 ± 0.9	17.8 ± 0.4	n.d.*	15.4 ± 0.3

\* FeO = FeO + Fe<sub>2</sub>O<sub>3</sub>

\*\* n.d. = no data

dle Miocene basaltic rocks, the Prineville chemical type of Uppuluri (1974) and the Bear Creek basalts of Goles (1986), that form the ridges east of Lone Pine Flat and that were erupted perhaps 3 m.y. later than the Smith Rock basalts.

Trace-element data corroborate this diagnosis (Obermiller, 1987). Rare-earth element plots of basaltic rocks from the Gray Butte complex (and other central Oregon silicic centers, including Powell Buttes and Cline Buttes) show light-rare-earth enrichment of 70 to 150 times chondrite (Figure 9), with Ce/Yb ratios of about 10. Such enrichments are slightly greater than most tholeiitic island-arc basalts.

The rhyolites and tuffs of the Gray Butte complex show similar signatures (Figure 9). They are peraluminous and corundum normative (Obermiller, 1987). They have substantial negative europium anomalies, suggesting that they were derived by fractionation (Obermiller, 1987) or that oxidation and dissolution have altered the original europium content of the rock. There is excellent evidence for the presence of an epithermal system at depth beneath Gray Butte, with the development of silica caps and brecciated zones near the western base of Gray Butte (Gray and Baxter, 1986). However, this hydrothermal circulation may not have substantially altered the surface rocks from which isotopic samples were taken.

#### THE ORIGIN OF THE GRAY BUTTE COMPLEX

According to Obermiller (1987), the best model for the origin of the Gray Butte complex basaltic andesites and rhyolites is fractionation of basaltic parental magmas of similar composition to the associated olivine-bearing tholeiitic basalts. The spectrum of basaltic

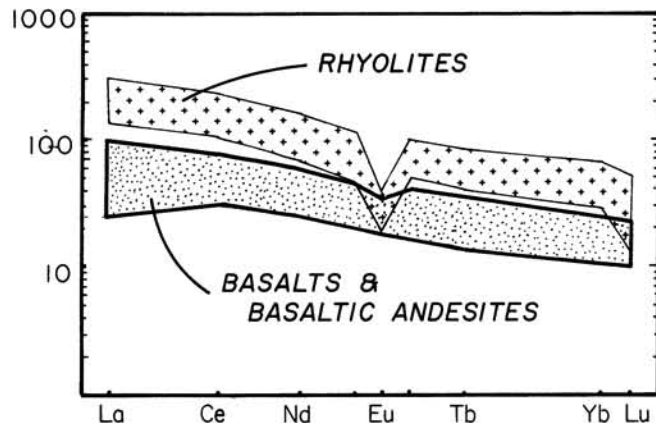


Figure 9. Rare-earth-element plots for rocks of the Gray Butte complex (after Obermiller, 1987).

compositions can be approximated by Rayleigh fractionation of varying amounts of olivine and plagioclase, with lesser clinopyroxene fractionation. Models of derivation of rhyolites by partial melting of altered or fresh basalts resulted in lower alumina contents than present in Smith Rock rhyolites. Rayleigh fractionation of evolved olivine tholeiites can produce most rhyolitic compositions at Smith Rock and Gray Butte (Obermiller, 1987). However, isotopic data suggest that considerable crustal contamination affected the Gray Butte complex. Values for <sup>87</sup>Sr/<sup>86</sup>Sr ratios of basalts beneath Gray Butte range from 0.7036 to 0.7072, with most values in the 0.704 range (Obermiller, 1987).

Rhyolites have considerably higher <sup>87</sup>Sr/<sup>86</sup>Sr ratios. The Gray Butte rhyolite yielded a value of 0.7101, and values for other rhyolitic rocks vary from 0.7068 to 0.7128 (Obermiller, 1987).

The Gray Butte complex samples have Nd and Sr ratios that plot to the right of the oceanic correlation line and in a field of lower Nd than island arcs, including the Cascades (Figure 10). Contamination by either seawater-altered oceanic rocks or continental detritus or the presence of an enriched magma source could cause this result. Lead isotopic data also suggest a crustal component in Gray Butte complex magmas (Figure 11). These plots indicate substantially greater upper crustal involvement in the Gray Butte complex than in the Cascades.

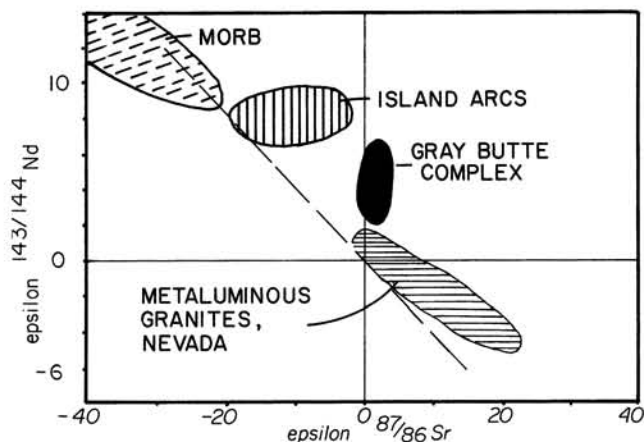


Figure 10. Plot of <sup>87</sup>Sr/<sup>86</sup>Sr and <sup>143</sup>Nd/<sup>144</sup>Nd isotopic ratios. Gray Butte complex samples show substantial evidence of upper crustal contamination (after Obermiller, 1987). Granite data are from Farmer and DePaolo, 1984. Diagonal line is trend for oceanic rocks. MORB=mid-oceanic ridge basalt.

#### IMPLICATIONS FOR THE TECTONICS AND CRUSTAL EVOLUTION

The nature of the involved crust is a bit problematic. No pre-Tertiary basement is known in this immediate area, and all indications are that the Deschutes basin upon which the Gray Butte complex is built is a thinly crusted product of back-arc extension and Basin and Range rotation (Smith, 1986; Obermiller, 1987). Although a single fusulinid-bearing limestone cobble was reported from the Smith Rock tuff (Thompson and Wheeler, 1942), it is likely that this rock originated in Crooked River gravels transported from the Grindstone terrane, rather than being a xenolith transported upward in Smith Rock tuff (Obermiller, 1987).

However, the isotopic evidence for some degree of upper crustal contamination of the Gray Butte complex is substantial. It suggests that Paleozoic/Mesozoic accreted terranes exposed in the Mitchell and Izee areas to the east and southeast, respectively, and also exposed along the Hay Creek anticline in the Hay Creek canyon area only 12 mi to the northeast, may also extend under the Gray

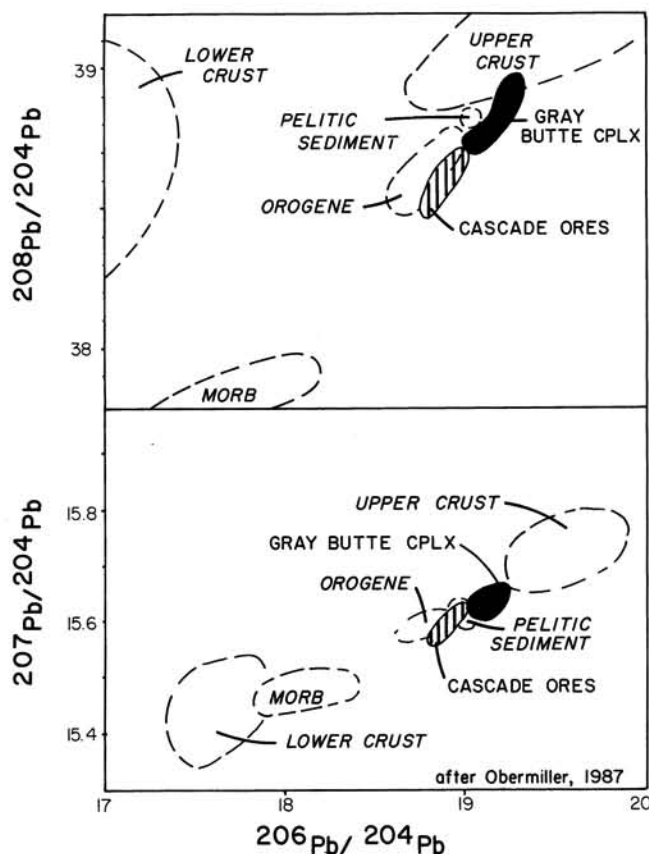


Figure 11. Plot of lead-isotopic ratios for the Gray Butte complex (after Obermiller, 1987). Gray Butte samples show evidence for substantial upper crustal contamination and plot on a mixing curve between upper crustal rocks and island-arc basalts.

Butte area. Alternatively, tuffaceous rocks and basinal deposits of the Clarno and John Day Formations may have contributed to or produced silicic shallow crustal melts in response to basaltic magmatism related to back-arc and Basin and Range-related extension. The probable oceanic nature of the first alternative and, likely, small changes from oceanic isotopic ratios suggest that the second alternative—contamination with altered Clarno and John Day volcanic and volcanoclastic materials—is the better model, although it is less than ideal.

#### ACKNOWLEDGMENTS

Most of the information in this paper is from the thesis of Walter Obermiller (1987). This paper's conclusions, however, are those of the author. Review by Jerry J. Gray, Oregon Department of Geology and Mineral Industries, is gratefully acknowledged.

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## New report on bentonite in Oregon released

A comprehensive report on bentonite in Oregon, its formation, industrial uses, and occurrences, has been released by the Oregon Department of Geology and Mineral Industries (DOGAMI). The report is intended to serve as a basis for further study and exploration and for the development of bentonite as an industrial-mineral resource in Oregon's economy.

The study concludes that exploration opportunities for commercial bentonite and the potential for large deposits exist in Oregon. It also indicates that there are West Coast and Pacific Rim bentonite markets that Oregon could supply. Preliminary analyses show that Oregon bentonites have a wide variety of physical properties that could serve a wide spectrum of industrial uses.

*Bentonite in Oregon: Occurrences, Analyses, and Economic Potential*, by DOGAMI geologists Jerry J. Gray and Ronald P. Geitgey and DOGAMI geochemist Gary L. Baxter, has been published as DOGAMI Special Paper 20.

The report consists of a 28-page text that describes bentonite as a rock and a commodity; the bentonite industry and trade, including exports; Oregon's bentonite industry and the resource potential of the state; and the laboratory testing of 152 samples collected for this study. The text is accompanied by three separate plates, one map and two tables: The compilation geologic map shows sample locations and geologic units deposited in basins in eastern and parts of western Oregon. One table lists tonnages of domestic uses and exports of bentonite and fuller's earth in 20 use categories and over a period from 1975 to 1986. The second table describes all samples, their locations, the nature of the sample sites, and the results of physical and chemical tests and X-ray diffraction mineralogy.

The new report, DOGAMI Special Paper 20, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201-5528. The price is \$6. Orders under \$50 require prepayment.

# Collecting fossils in Oregon

by Melvin S. Ashwill, amateur paleontologist, 940 SW Dover Lane, Madras, Oregon 97741\*

## INTRODUCTION

Hanging on my study wall is a clock I have made from a flat slab of rock that has on its surface a magnificent large fossil leaf from an ancient sycamore tree. Of course, the clock is a delight to me, yet each time I look at it, I experience a tinge of regret because I know that this lovely and significant fossil will never be where it properly belongs—in a research collection to record the development of the sycamore family. It is not now suitable for such a collection because no one knows for sure its age or where it was found. An old friend collected this and many other quality specimens but did not put any identifying marks on this one. At his death, his son gave me several pieces from the collection. I think that I know where this one came from, for I know his collecting habits, and the rock matrix is familiar to me. In the field of science, however, "I think," "probably," and "I guess" are enough to fling a shadow of doubt that reduces evidence to worthlessness. Therefore, this beautiful fossil is reduced to being "only a curiosity." Lesson: Immediately upon collecting a fossil, number and reference it in some permanent manner so that locality and other important information pertaining to it are not lost.

A fossil collection can be a source of pleasure in many ways. The specimens themselves are beautiful. As evidence of evolution as well as changing ecological conditions through time, they provide food for thought. The collecting process itself gets the collector outdoors to many different areas and provides healthful exercise. Beyond these purely selfish concerns, however, your collection can serve a useful purpose. If you are careful as you collect and identify your fossils, if you keep good records, and if you share your information with other fossil collectors—both amateur and professional—as well as with others interested in learning about paleontology, your fossils can also serve to advance knowledge. This article tells you how to get started in fossil collecting—and how your fossils may be useful to others.

## BASICS OF FOSSIL FINDING

If all of the readers of this article were to start driving their cars at the same time, and then if they all were to stop their cars at the same moment, get out, and spend two hours digging for fossils wherever they happened to be, Las Vegas oddsmakers should be able to make a lot of money by betting that none would find a fossil—even in Oregon, one of the premier fossil grounds of the world. Yet, armed with proper knowledge, any person living in Oregon could probably drive to a fossil site in less than an hour from his or her home. A paleontologist friend from Indiana is envious. "Why, you could ride a bicycle from your house to this site," he exclaimed of a locality near my home.

So, how do you locate fossils? First off, don't waste your energy digging for fossils unless you have been given good reason to believe there are some at hand. In Oregon, you can rule out huge expanses of two kinds of geologic environments. You can be fairly certain, for example, that you will find no fossils in lava rock. It should be noted, however, that most rules have exceptions. For instance, Lava Cast Forest near Bend has fossil impressions of tree trunks that were buried in lava, and near Blue Lake in Washington, a mold of the bloated carcass of a rhinoceros exists in a basalt flow. Furthermore, areas of topsoil, the loose, fine-grained dirt that collects in valley



*Pleistocene fossil whale being excavated near Port Orford in Curry County under the supervision of Dave Taylor, Northwest Museum of Natural History Association. Shown from bottom to top of photograph are Meredith Myllenbeck, Lana Stricker, and Clair Stahl.*

floors, are not prime sites. On rare occasions, topsoil preserves fossils, but generally it does not. The processes that move a fossil from bed rock into topsoil usually also reduce the fossil to dust—or at least to fragments.

So, what are the likely areas? Wood, leaves, flesh, bones, and even teeth, if exposed to the elements, will decompose with time. It is no surprise, then, that most well-preserved fossils are found in rocks that originally were a mud that protected the organic material from oxygen and therefore bacterial decay. If the remains survive this initial step of burial, minerals in ground water may permeate and harden them. Fine-grained sandstone (or siltstone, mudstone, or shale) is one of the fossil-hunter's favorite rocks. For marine fossils, another likely tomb is limestone. Most limestone is composed of remains of sea creatures. The third promising type of host material in Oregon (mainly central and eastern) is what was originally light-colored volcanic ash that rapidly buried plants and animals with thick deposits.

Because of the flat structure of minerals in fine-grained mudstones and shales, these rocks often split into flat slabs. A paleontologist's right foot

\*Mel Ashwill maintains a private fossil museum behind his home, which is at the northwest corner of the intersection of Dover Lane and Highway 97 about 2 mi south of Madras. He is willing to show the museum to interested persons or groups by phone appointment only. His phone number is (503) 475-2907.



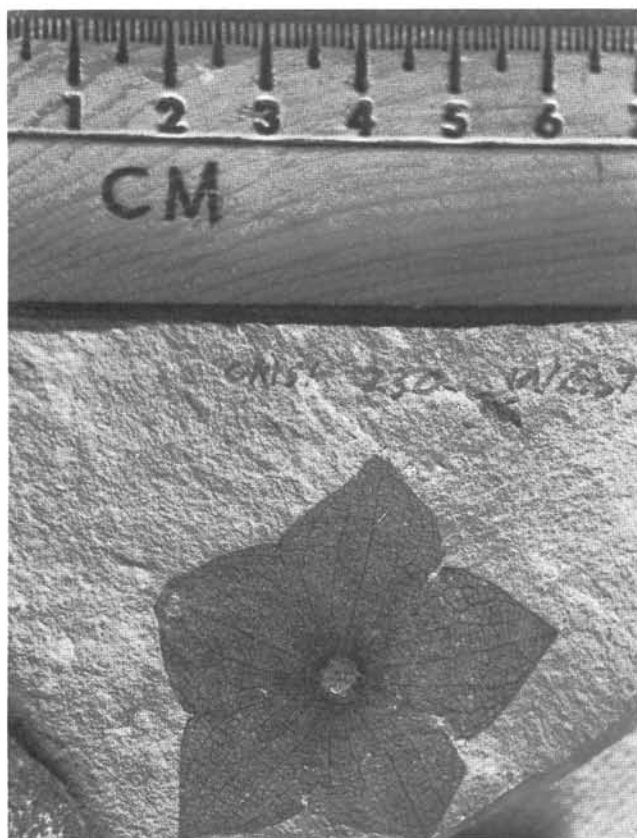
automatically eases off the gas pedal when he or she passes a roadside exposure of platy, sedimentary rocks. Many are fossiliferous.

Diligent searching in favorable areas will, at length, probably lead to the discovery of fossils. However, there is a short cut used by most fossil finders. Somebody shows or tells them where to find the quarry (pun intended)! Other collectors know of likely sites and are willing to share their knowledge. Hunters, farmers, ranchers, and geologists all spend a lot of time on foot in out-of-the-way places. They frequently locate new areas and often will, if asked, help the paleontologist. Additionally, as geologists publish the results of their field work and often give exact locality coordinates, time spent reading geological papers will often produce helpful information for you. A two-line mention in a geological paper can take you to an exciting find.

### HELPFUL PUBLICATIONS

There are even books that will direct you to fossil sites. A reference, informally known as the "Blue Book" among fossil collectors, is entitled *Fossils In Oregon*. Edited by geologist Margaret L. Steere, the 227-page book was published by the Oregon Department of Geology and Mineral Industries (DOGAMI) as Bulletin 92 and can be purchased from its main office (editor's note: see address on inside front cover of this issue. Also, be advised that the glue binding the book is not very durable, so that the book, while filled with useful information, tends to fall apart easily). The book contains directions to and descriptions of fossils from more than 35 fossil locations in Oregon. It is copiously illustrated.

Two other books on Oregon paleontology are indispensable to anyone interested in the state's fossils. The wife-and-husband team of Elizabeth L. and William N. Orr (University of Oregon paleontologist) authored both the *Handbook of Oregon Fossils* (1981) (available at private bookstores and from the authors at P.O. Box 5286, Eugene,



Flower of extinct tropical vine (*Holmskioldia* sp.) of Eocene age. Fossil was collected from the West Branch Bridge Creek near Mitchell.



Mastodon tooth taken from bog deposits near Tualatin, Oregon. Photo courtesy of the Oregon Museum of Natural History.

Oregon 97405) and the *Bibliography of Oregon Paleontology, 1792-1983* (1984) (available as Special Paper 17 from DOGAMI).

Although it does not contain precise locality directions, the 285-page *Handbook of Oregon Fossils* is a gold mine of well-organized information. Generalized discussions of fossil plants, pollen, invertebrates, trace fossils, arthropods, fresh-water fish, birds, marine vertebrates, and land vertebrates include many illustrations that will help you in identification of your fossils. The bibliography at the end of the book can help you find new localities to explore.

*Bibliography of Oregon Paleontology, 1792-1983*, also by the Orrs, is a compilation of references containing information about Oregon fossils up to 1984. Its 82 pages list more than 1,200 references, most of which will help guide the collector to at least one specific locality.

### OTHER INFORMATION SOURCES

Visits to museums can lead you to more information. Many small local museums exhibit a few local fossils and often include the name of the collector. Natural history exhibits will help familiarize you with what is available and what you should be looking for. You can ask other collectors about associations or societies where you can meet people with interests similar to your own. You can subscribe to local or state publications such as *Oregon Geology* that publish papers related to local paleontology. If you are really serious about your fossil collecting, you can contact local community college geology teachers or university professors for information about fossil-collecting sites.

### PROSPECTING TECHNIQUES

A few paleontologists publish such complete locality directions, including photographs, that they enable the collector to drive or walk



directly to the site and begin collecting. More commonly, however, directions will consist of coordinates (township, range, section, and quarter section) and perhaps a brief description of strata above and below the site. This will get the collector to within about an eighth of a mile of the locality, still leaving a vast area to be covered in the search.

A common technique followed by collectors in searching the terrain for a fossil site, which may be only a small exposure, is similar to the process often used by precious-metals prospectors. Unless it is known that the exposure is actually a stream bed, it is better to search the sides of the hills a little bit above the valley floor. A fossil-bearing ledge uncovered by erosion in the valley bottom is likely to be covered by topsoil to a considerable depth. On a side-hill site, as the fossils weather out, they are moved downslope along with other rocks and soil. On their journey to the bottom of the hill, the fossils are constantly being reduced by weathering and abrasion to smaller and smaller pieces and eventually, of course, are no longer recognizable as fossils. The fossil hunter needs to traverse back and forth on the hillside, starting just above the valley floor, and gradually climb the hill while scanning the ground closely.

Usually, the first sign of the object of the search is a small fragment, so the collector must closely examine the surface of promising rocks. What should one look for? Usually regular shapes or lines; smooth surfaces and contours; curves rather than jagged edges; contrasting color patterns on rock surfaces; and repeating segments such as ribs, growth lines, and leaf veins. Actually, any rock that stands out as being somehow different from the other local rocks bears a second look. A previous excavation pit, though grassed over and partially filled, often tattles as to the location of the site. In the case of vertebrate fossils, teeth are the hardest components of the skeleton, and smaller fragments may have settled to the bottom of the drainage area. Color is often used to distinguish fossils from rock matrix. Cape Blanco is so named because of the white Pleistocene shells exposed there. Vertebrate fossils of calcium phosphate often preserve with a typical carmel brown or even bluish color.

After the first fragmentary find, the collector needs to slowly work uphill, following a trail of increasingly larger fragments to the fossil-bearing outcrop, the bonanza! Sometimes the outcrop itself

is covered by topsoil, and the only evidence as to its location is the fact that at a given point, the uphill trail of fragments gives out. Digging is now warranted. Fossil-bearing outcrops may be found at any point on a hillside, but it is remarkable how often they occur at the brow of a knob—and, in Oregon, how often they occur in strata just below a lava flow.

Light conditions can affect the visibility of fossils in the field. Low, slanting light seems to emphasize the flat and curved surfaces of the specimens. Morning and evening hours provide this condition. How serendipitous it is that these hours also allow one to avoid the heat of the day.

"You find what you are looking for" is a truism that is abundantly illustrated in fossil collecting. Earlier large-vertebrate collectors bypassed some areas rich with small specimens, eggs, and nests. They were looking for large bones and skulls, and they found them. Now that the significance of the smaller items is recognized, they too are being recovered in quantity.

Another "old geologist" saying is, "I wouldn't have seen it if I hadn't believed it." A friend who is an avid and very successful big-game hunter says he envies me because in all his life he has never recovered a single artifact or fossil, while I have found many. When we hunted together, he always got the game, and I always came away with a few interesting rocks in my pockets. When I guide a class to a fossil site, members often express puzzlement as to just what it is for which they should be looking. My verbal descriptions help a little, but once the students have actually seen a specimen, others usually turn up, with no more help needed.

#### HOW TO COLLECT

Only rarely does a fossil site produce quality material lying loose on the surface of the ground. When such a place is located, however, collecting is easy, and few tools are needed. A backpack or sack to carry the specimens, some newspaper for wrapping them, a permanent-ink felt-tip pen for marking them, and a geologists' hammer will do nicely.

More commonly, light digging is necessary. Removing partially visible specimens from exposed ledges will require some sort of sharp-edged bar or chisel and possibly even a shovel and pick. You



*Fossil skull of a Pleistocene bison taken from a bog near Salem. Photo courtesy of the University of Oregon Museum of Natural History.*



*Hugh Wagner works to excavate a juvenile rhinoceros jaw from the wall of Blue Basin in the John Day Fossil Beds National Monument. Inches beneath the crumbly, weathered surface, the rock is hard, making excavation of the brittle fossils a delicate task. Photo courtesy of U.S. National Park Service.*

will note that whisk brooms, fine chisels, knives, plaster of Paris, and surveying equipment have not been mentioned. There are times, of course, when all of the above, and more, are needed.

If you are lucky enough as an amateur to come across a really significant find, such as a partial skeleton fossilized in place, for example, that might call for more sophisticated methods of collecting, the best service you can do for yourself and for science is to (1) enjoy your find ("Oh," "Wow," and "Just look at that," are in order); (2) write down directions to your find and mark the location with something such as a handkerchief on a bush or spray paint on a rock so that it is easily visible; (3) photograph the exposure; and (4) refer your information to a professional paleontologist. It is unlikely that you will get everything right if you try to remove the fossil yourself. Without a doubt, the professional who comes out to collect the specimen will welcome your help in its recovery. You will get the thrill of collecting and learn how it is properly done, and the fossil will be removed intact with the proper documentation. More importantly, the orientation of a fossil in the matrix may be a significant piece of research information. The fossil should not be disturbed until this is recorded.

Where do you find the professionals? There are at least eight actively working in the state of Oregon: William Orr, Department of Geology, University of Oregon, Eugene; Guy Rooth, Department of Geology, Western Oregon State University, Monmouth; David Taylor, Northwest Museum of Natural History Association, Portland; Richard Thoms, Geology Department, Portland State University, Portland; Theodore Fremd, Paleontologist, John Day Fossil Beds National Monument, John Day; Jane Gray, who specializes in the study of pollen and spores (micropaleobotany), Departments of Geology and Botany, University of Oregon, Eugene; Gregory Retallack, an expert on paleosols (fossil soils), paleobotany, and fossils in general, Geology Department, University of Oregon, Eugene; and A.J. Boucot, who has an extensive background of work with marine invertebrate fossils, Departments of Geology and Zoology, Oregon State University, Corvallis.

#### WORD OF WARNING

Do not accidentally walk on fossils. If you find fossil fragments on the surface of the ground, carefully scan the area before doing any more prospecting. Small vertebrate fossils are often carelessly destroyed by foot crushing.

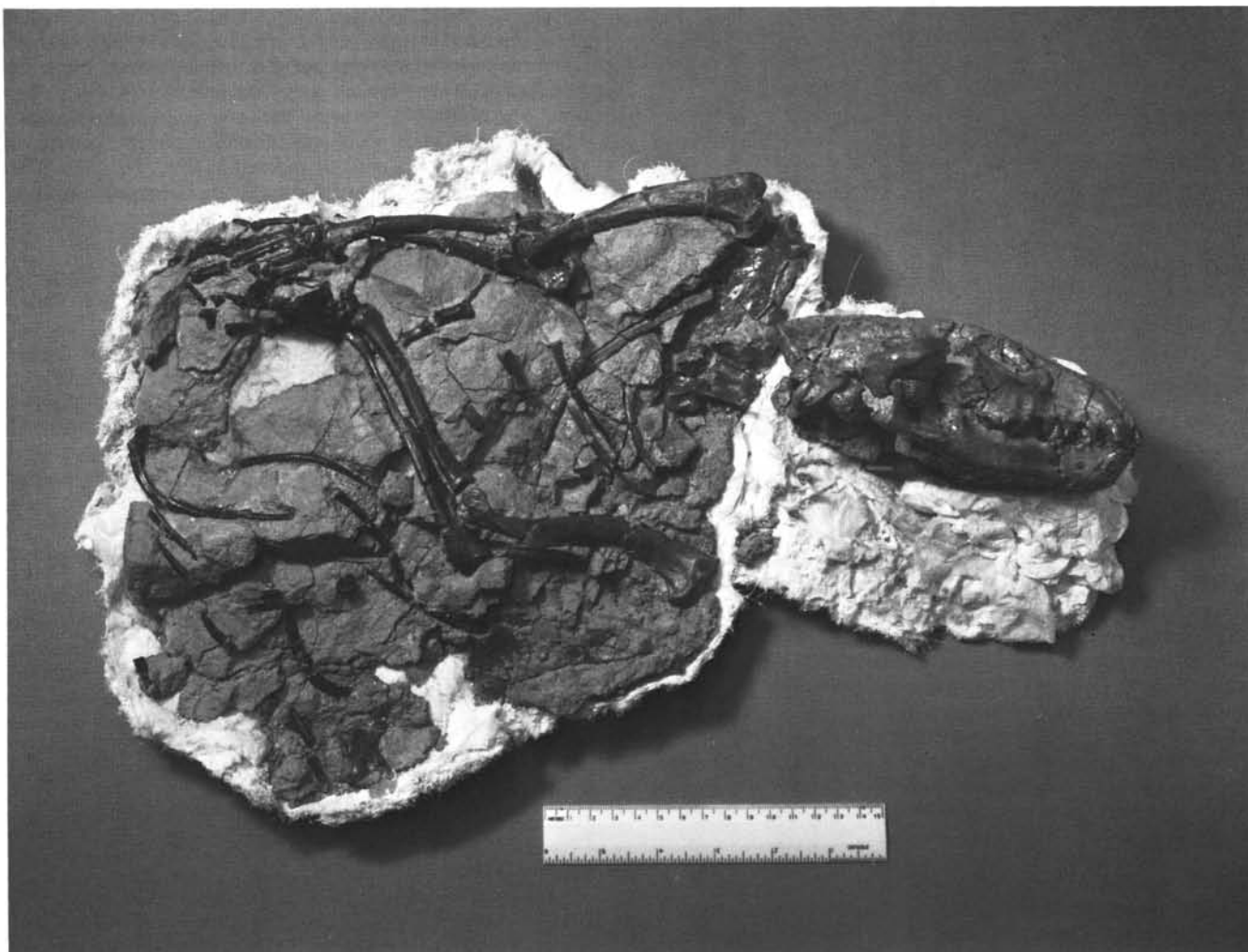
#### HANDLING FOSSILS

Your first charge, after recovering fossils, is to return them to your home without damaging them. Careful and tight wrapping in newspaper is the usual method of protection. Before you wrap them, however, you should mark them with the location. In your laboratory area, if you have unmarked boxes of fossils from more than one site, being sure of the source is a problem. Take a permanent-ink felt-tip pen with you on your collecting trips. Mark specimens directly, and again mark the outside of the box or sack before leaving the site.

Large museums hire technicians, called "preparators," who do the demanding detailed work of trimming, cleaning, and repairing fossils. In your jack-of-all-trades capacity, however, you will do this. In the case of vertebrate and invertebrate fossils or petrified wood, this usually means removing the fossil completely from the matrix. An exception might be when you plan to exhibit the fossil partially exposed but remaining attached to its rock matrix, which is an effective technique. In either event, exposure of the fossil demands careful and sometimes tedious work. In the case of vertebrate fossils, the amateur would do well to consult a professional paleontologist before tackling this specialized task. Much of such a job is often done with sharp metal edges, such as small chisels, picks, knives, vibrator tools, engraving tools, and drills. Water or other solvents are sometimes a help in softening the rock. Trial and error will help determine which of these tools to use, and advice of other collectors is an aid. In the case of leaf imprints on rock, trimming away



*William N. Orr, paleontologist at the University of Oregon, discusses a fossil mammoth tusk at the University of Oregon Museum of Natural History. Listening is Dolph James, former Director of the Eugene, Oregon, Branch of the Oregon Museum of Science and Industry. Mammoth tusk is from Pleistocene gravels near Roseburg.*



*Fossil dog (Mesocyon sp.), latest Oligocene/early Miocene, from the Turtle Cove Member of the John Day Formation at the John Day Fossil Beds National Monument. Specimen was collected in 1982 by Hugh Wagner. Note plastic jacket surrounding fossil. This is a good example of an extremely fragile specimen that required full laboratory facilities to prepare, identify, and study. Photo courtesy of U.S. National Park Service.*

excess matrix is usually the main task and is accomplished with hammer and chisel, pliers, vises, and rock saws. Leaf fossils with a relatively soft matrix can be trimmed on a table saw with a masonry blade. Harder specimens must be worked with a lapidarist's diamond-edged saw, using water, not oil, as a coolant.

Specimens that have been coated with shellac or similar clear finishes are often seen on display. You should be aware that such treatment often enhances the contrast and appearance of the fossil but can detract from its scientific usefulness. When you put such a specimen under a microscope, you have to look through the coating, and some detail is lost. Some fossils are so highly fractured that it is necessary to coat and impregnate the material with bonding agents to hold the pieces together. In such cases, you must be careful that surface details are not obscured. A dilute solution of polyvinyl acetate in acetone is superb for soaking a fossil and binding it together without leaving a thick residue on the surface.

#### **LABELING AND RECORDING**

In order to be able to positively relate a fossil to its locality, an organized form of marking and recording is needed. Commonly, museums and collectors alike use permanent ink on a small spot of white paint to mark specimens in a type of shorthand code.

Typewriter "whiteout" is sometimes used for this purpose but may flake off unless covered by shellac. Each of your localities should be given a number that is recorded in a notebook along with a complete set of locality directions. This locality number is marked on the appropriate specimens. It should be prefixed with the initials of the collector or the institution housing the collection. An example is "UO-1407," which is University of Oregon Museum of Natural History locality number 1407. If the specimen is an important item, such as a type specimen cited in the literature, it should also be marked with a catalog number.

As you record your locality information, photographs, written directions, and maps are helpful. Indispensable are geographic coordinates. To determine the coordinates, find the site on the largest scale topographic map available and mark it on the map with a small "x" or dot. This will enable you to determine which quarter of which section it occupies. The coordinates consist of (1) the quarter of the quarter section in which the site is located, if the map scale permits such precise location; (2) the quarter section in which the site is located; (3) the section number; (4) the township number; and (5) the range number. An example is SW  $\frac{1}{4}$  NE  $\frac{1}{4}$  sec. 10, T. 12 S., R. 18 E., which means the southwest quarter of the northeast quarter of section 10 of Township 12 south of the Willamette Base Line and in Range 18 east of the Willamette Meridian.





This magnificent specimen is a fossil scallop (*Patinoptecten propatulus* [Conrad]) from the Miocene Astoria Formation at Newport, Oregon. Photo courtesy of the University of Oregon Museum of Natural History.

## IDENTIFICATION

Once you have collected and prepared your specimens, they should be classified and identified. Identification of some specimens, such as those of new species, for example, or those whose features are not readily assignable to a particular taxon, may require the resources of our professional allies.

The common genera and species can often be identified by comparison to either the illustrations and descriptions in the helpful volumes previously mentioned or by referring to special studies in published papers found in science libraries at major universities in the state.

Two other publications are also helpful in your identification of fossils. *Fossil Mollusks of Coastal Oregon*, by Ellen James Moore (1971), is indispensable to anyone collecting invertebrate fossils of the area. Its 64 pages are crammed with excellent photographs of specimens. Moore's book is published by the Oregon State University Press, Corvallis, and may also be found in science libraries. *Common Fossil Plants of Western North America*, by William Tidwell (1975), is a fine treatment of the subject. It is aimed at the amateur but is widely found on professional paleobotanists' bookshelves as well. It has 197 pages of illustrations, descriptions, and discussions of fossil plants and may be purchased at university bookstores, museum giftshops, and bookstores in general.

Professional paleontologists are usually willing to help the serious amateur in identification, provided the collector does not overload these busy and highly trained people. Partly this is because many of them are generous souls and partly because this sharing is a two-way street. Amateur collectors sometimes make significant finds that are a tremendous help to professionals.

## PHOTOGRAPHING

Among the reasons for keeping a photographic file of selected fossils in your collection are the following: (1) Folios of photographs are compact. It is quicker to refer to a well-organized photo file than bulky trays of specimens. (2) Photos are useful for publication and lecture. (3) A certain number of your specimens will inevitably be lost because they may deteriorate or break, they may be misplaced, some may be borrowed and never returned, or some may be given to a colleague. A good photograph, however, keeps the needed data available.

Presently, publishers of scientific papers seldom print color photographs. Black-and-white glossy photographs with the best possible contrast and detail and including an object (often part of a metric ruler) for scale are used. Color slides are fine for lecturing. Two

floodlights (250 to 500 watts each) aimed at the subject from opposite sides at low angles provide effective lighting. A slow shutter speed combined with a small aperture opening and the use of slow film (low ASA number) help to get maximum detail. For publication, where possible, showing the specimen at natural size is desirable. Microscopic specimens, of course, need enlargement, and very large specimens must be reduced in size. You should use a tripod or camera stand to avoid blurring of the image due to vibration.

## SHARING YOUR INFORMATION

No matter what your collection holds, it will not advance the field of paleontology until its contents are known by other students of the past. Some collectors give talks to schools and civic groups. Many eventually donate significant finds or entire collections to museums. Another worthwhile method of disseminating information on what you have found is through publication. Many serious collectors have published papers in scientific publications, and by doing so have made contact with specialists who have been able to use information from their collections and in turn have helped with identification.

## WHAT WILL EVENTUALLY HAPPEN TO YOUR COLLECTION?

If you do not dispose of your collection while you are alive, it will be done later by someone else. No one knows as well as you do where the specimens will be best used. Don't wait too long. I have been made uncomfortable at times by seeing good collections left to the care of heirs who allow them to languish, become scattered, and eventually be lost. Some heirs do not place a great deal of significance on the collections and allow them to be removed piecemeal as curiosities. Some have ended as playthings of children.

## WHAT IS THE MONETARY VALUE OF YOUR COLLECTION?

The main value of a collection is in the information it provides. Its actual value on the market is highly overrated by most laymen. Lifetime collections of large size and significant finds have sold for less than the actual out-of-pocket expenses involved in collecting them. If the collector's time were added into the collecting cost, probably no sale of collections would show a break-even figure.

Because of these facts and the public's general misconception of fossil dollar values, museum curators are often put in the uncomfortable position of being asked to appraise the value of a collection and then finding themselves maligned for supposedly trying to undervalue the items so they can get the collection cheaply.

## LAWFUL COLLECTING

Collecting of fossils on public lands may be restricted by the local or regional administrator of the supervising agency. No collecting is permitted in national parks except by qualified institutional groups or their representatives. In USDA Forest Service (USFS) or U.S. Bureau of Land Management (BLM) areas, permission to collect is usually granted if the specimens collected are to be used for hobby or scientific purposes.

How much collecting should be allowed on federally owned lands has long been an unsettled issue. The balancing of five different needs is a thorny problem. Those needs are (1) the need to protect scientifically important or rare specimens from perpetual loss; (2) the need to protect fossil deposits from massive overcollecting by commercial collectors; (3) the need of scientific researchers to have access to fossils; (4) the need of the tax-paying public for recreational or hobby collecting of limited numbers of fossils; and (5) the need to avoid destruction of fossils by weathering. Despite years of conference within and between federal agencies, the issue remains unsettled and is mostly dealt with by individual land managers.

(Continued on page 94, *Fossils*)



# Thunderegg collecting in Oregon

by Paul F. Lawson, mineral collector and retired Supervisor, Mined Land Reclamation Program, Oregon Department of Geology and Mineral Industries

## HISTORY

The Thunderegg was designated Oregon's official state rock by the Oregon Legislature in 1965. Its selection was supported by a 2 to 1 vote by members of the mineral and gem clubs of Oregon and by the patrons of the Oregon Museum of Science and Industry (OMSI).

The Thunderegg has long been important to Oregonians. According to ancient Indian legend, when the Thunder Spirits living in the highest recesses of snowcapped Mount Hood and Mount Jefferson became angry with one another, amid violent thunder and lightning storms they would hurl masses of these spherical rocks at each other. The hostile gods obtained these weapons by robbing the nests of the Thunderbirds of their eggs, thus the source of the name "Thundereggs." The mountains are still key landmarks in the beautiful High Cascade Range, and millions of Thundereggs are on the lower lands as evidence of the legend and for all to enjoy.

The Thunderegg has been highly prized by collectors, lapidarists, jewelry makers, and interior decorators for nearly 100 years. In 1893, Dr. George F. Kunz, Tiffany's famed gem authority, estimated that as much as \$20,000 worth of opal-filled eggs from one Oregon deposit had been marketed in 1892. Since the mid-1930's, thousands of visitors from every state in the Union and many overseas countries have come to Oregon to hunt Thundereggs. Many Oregonians have also joined them.

Thundereggs are made into beautiful jewelry, especially bolo ties and pendants, pen stands, bookends, and decorator pieces. Their value ranges from about \$1 per slice or half egg to well over \$100 per slice or single cabochon. Thundereggs and their products can be purchased through magazine ads; at gem or rock shows; from tailgaters at outdoor events; at gem or lapidary shops; and at airport, motel, hotel, and restaurant gift shops or counters.

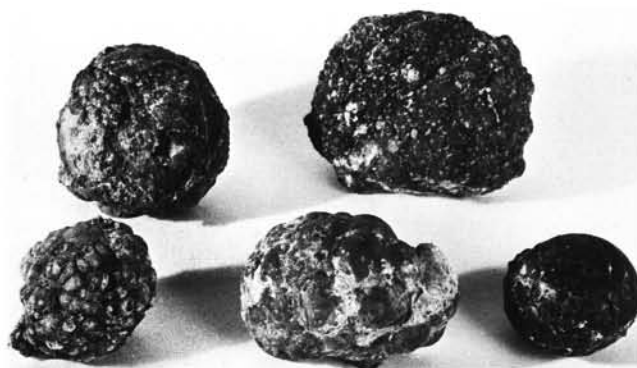
## HOW THUNDEREGGS FORM

Although the Thunderegg is an honorary rock by Legislative decree, it actually is not a rock. It is a structure, sometimes a nodule, sometimes a geode, occurring in rhyolite, welded tuff, or perlitic rocks. However, without question, the Thunderegg is by far the most popular "rock" in Oregon.

Scientists do not agree on the processes forming Thundereggs. Some insist that the characteristic and unique internal pattern of typical Thundereggs is due to expansion and rupture of rock by gases. Others claim the pattern is due to desiccation (drying) of a colloid or gel. Whatever the process, however, after the cavity that contains the egg is formed, further development is extremely variable in the amount of time needed to complete the egg, in the degree and type of infilling, and in other physical characteristics. Thundereggs range in size and weight from less than an inch and under 1 ounce to over a yard in diameter and over a ton in weight. Most eggs collected are between 2 and 6 inches in diameter.



Digging for thundereggs in the Blue Beds at Richardson's Recreational Ranch. Photo courtesy of Lewis Birdsall.



*Outside appearance of Thundereggs from different localities in Oregon: Madras-Prineville area (upper and lower left), southeastern Oregon area (upper right), Burns area (lower middle), and Lakeview area (lower right).*

### HOW THUNDEREGGS LOOK

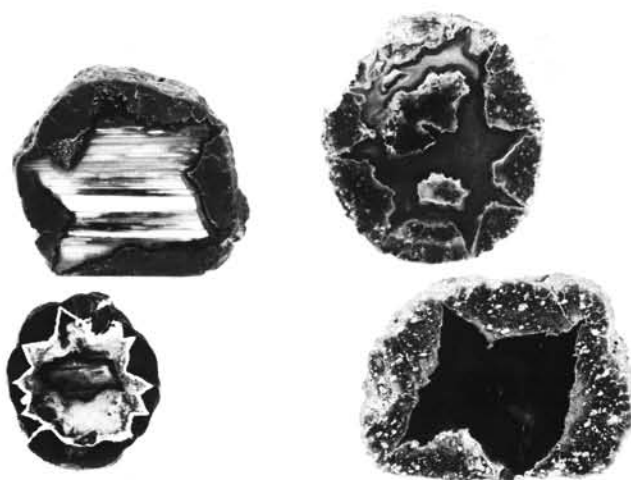
Typically, an egg has a russet-colored outer shell that is often knobby and often has a characteristic ribbed pattern. Frequently, the inside of the outer shell has a relatively thin intermediate or transitional lining. This is sometimes composed of an iron or manganese compound, often with a thin coating of opal or chalcedony. Sometimes only opal or chalcedony is apparent. Finally, the center of an egg is usually filled with chalcedony or opal and may or may not have inclusions, pattern growth, or crystals. In some variants, the egg may be hollow or may have a thin layer of chalcedony coating the interior. This layer sometimes is topped with a coating of small quartz crystals.

Growths of alga-like tubes, or plumes, or "moss" of manganese or iron compounds or of clay may be free standing or partially or wholly embedded in chalcedony. Some eggs with plumes ("flowers") in chalcedony are among the most valuable specimens. Several zeolites have been observed or reported in Thundereggs; clinoptilolite is fairly common, and mordenite, natrolite, and mesolite have also been reported.

Thundereggs are sometimes found with fortification banding just inside the shell, then an area of horizontal layering, with the remaining central area filled with clear chalcedony or inward-pointing quartz crystals. Banding and layering vary in color, thickness, and content. Some layers are composed of a fibrous cristobalite (lussatite). Other eggs have a partial botryoidal filling of an opal form of low cristobalite. This opal is often fluorescent because of a low content of uranium salts.

One collecting site in Oregon has eggs filled with carnelian. At another, the filling may contain cinnabar, which colors it pastel to intense red. Some eggs are filled with pastel jaspers. Others may have any one of a variety of opal fillings that may be opaque blue, opaque red, translucent pastel blue, translucent yellow, translucent red, white, or colorless. Some of the opal can be faceted, and a small percentage is true precious opal.

Some eggs have well-developed calcite crystals encased in chalcedony, and others contain pseudomorphs of chalcedony after calcite. Some eggs have layering that is fanned from one edge, because the egg was rotated by earth movement while the filling was being deposited. This and other features suggest that the complete development of some eggs may have taken considerable time, and the filling-in of the egg may have recorded a series of geologic events. Some eggs contain brecciated rock fragments, while others show faulting, offset, and healing. One of the most unusual Thunderegg variants is up to 3 feet long and 2 to 3 inches in diameter and looks much like a fat gray worm. In some areas, it is common to find the characteristic chalcedony core weathered out of its shell.



*Typical inside appearance of Thundereggs that were cut and polished.*

If a complete egg is sawed in the right orientation, one or more conduits through which filling materials flowed may be found. The beauty and complexities of many of the cut and polished eggs explain why Oregon rockhounds have long been fascinated by Thundereggs.

### WHERE TO FIND THUNDEREGGS IN OREGON

Thundereggs can be collected at many sites in Oregon. Some localities occur in beautiful forested hill country, others in dry, desertlike terrain. It should be understood that Thundereggs have been eagerly collected in Oregon for fifty years. Therefore, on "free sites," collectors must expect to dig and work for Thundereggs. Proper equipment, including shovel, pick, and bar, makes the job much easier. The "fee" site will almost always have some preparatory work (overburden removal) done. Also, eggs may usually be purchased at the site office. Some places may have tools for rent.

### LOCATIONS

#### Madras-Prineville area

**White Fir Spring** (National Forest land; free site)

**Whistler Spring** (National Forest land; free site)

For current information on these sites, contact  
Prineville Ranger District  
2321 East Third  
Prineville, OR 97754  
(503) 447-3825

**White Rock (or Wildcat Mountain)** (National Forest land; free site)

For current information on this site, contact  
Big Summit Ranger District  
34885 Ochoco Ranger Station  
Prineville, OR 97754  
(503) 447-3845

A map of the area's free collecting sites (including sites for other rockhound materials) is available from  
Prineville Chamber of Commerce  
390 North Fairview  
Prineville, OR 97754  
(503) 447-6304.



Rarer formations in Thundereggs from the Priday beds (Madras-Prineville area): Green moss agate (top) and red, yellow, and orange plume agate (bottom).

Current information is also available from  
H.L. Elkins Gemstones  
833 South Main  
Prineville, OR 97754  
(503) 447-5547  
and from the following private (fee) sites:

**Richardson's Recreational Ranch** (fee site)  
Gateway Route, Box 440  
Madras, OR 97741  
(503) 475-2680  
(Combines old Priday and Kennedy Ranch beds. Also includes a variety of agate and jasper materials.)

**Hay Creek Ranch** (fee site)  
Ashwood Star Route  
Madras, OR 97741  
(503) 475-7237  
(Several egg beds and also other varieties of agate and jasper materials are available.)

**Lucky Strike Thundereggs** (fee site)  
P.O. Box 128  
Mitchell, OR 97750  
(503) 462-3176

#### Lakeview area

**Crane Creek** (free site)



Thunderegg from central Oregon showing a fracturing event during which jaspery breccia entered the Thunderegg. Photo courtesy John E. Allen, Emeritus Professor, Department of Geology, Portland State University.

For current information on this site, contact  
High Desert Craft Rock Shop  
244 North M  
Lakeview, OR 97630  
(503) 947-3237

#### Burns area

**Buchanan** (fee site)  
For current information on this site, contact  
Highland Rock and Gift Shop  
1316 Hines Boulevard  
Burns, OR 97720  
(503) 573-2995

#### Southeastern Oregon area

**Succor Creek** (free site)  
For current information on this site, contact  
Emil Wohlcke  
Chairman, Thunderegg Days  
707 Emison Avenue  
Nyssa, OR 97913  
(503) 372-3715

or

Bureau of Land Management  
100 Oregon Street  
Vale, OR 97918  
(503) 473-3144

**GOOD HUNTING!**



# Current assessment of earthquake hazard in Oregon

by Robert S. Yeats, *Department of Geology, Oregon State University, Corvallis, Oregon 97331*

Five years ago, very few people were concerned about major earthquakes in the state of Oregon. Historical damaging earthquakes had been recorded in the adjacent states of Washington, Idaho, Nevada, and California, but not Oregon. This lack of concern is expressed today in seismic zoning maps, which put the state of Oregon in a lower seismic risk category than adjacent states.

Today, the earth science community appears to have reached a consensus that Oregon has been struck by large earthquakes in the past and therefore that Oregon is likely to be subjected to large earthquakes in the future. There is no agreement among earth scientists on whether Oregon will be subjected to a magnitude 9 or only a magnitude 7 earthquake. Nor is there compelling evidence for past large earthquakes directly beneath the heavily populated Willamette Valley. But the evidence found in marshes in estuaries on the Oregon coast is compelling enough for reevaluation of seismic zoning maps and of the seismic safety of critical facilities such as power plants, hospitals, and dams.

In evaluating earthquake hazards, it is not enough to show that crustal deformation has taken place in the recent past, because such deformation could take place slowly and smoothly, unaccompanied by earthquakes. It is necessary to show that deformation occurred in sudden jerks, as it does during an earthquake.

In Oregon and Washington, scientists have now shown that coastal marshes and coniferous forests have recently undergone sudden subsidence that killed the marshes and forests by inundating them with sea water. Sand commonly found overlying the marshland sediments shows strong evidence of having been deposited by a seismic sea wave, or tsunami. Sand of this kind has been reported from the Salmon River and Alsea Bay, Oregon, and from Willapa Bay, Washington.

Many attempts have been made to account for the buried marshes by nonseismic processes, notably gigantic, 500-year storms or a slow rise in sea level. Sea-level change in the last 5,000 years does not appear to be large enough to account for the marshland burials. Marshes on the East Coast and Gulf Coast of the United States have been subjected to great storms in the past, notably hurricanes, but these marshes do not show evidence of rapid burial. However, marshes around the Gulf of Alaska and in southern Chile do show evidence of rapid burial, including burial after the 1960 Chile earthquake (magnitude 9.5) and the 1964 Alaska earthquake (magnitude 9.2). We cannot completely exclude the possibility that the marshes could have been mantled with sand by a gigantic Pacific storm occurring during a time of temporary sea-level rise in the last few thousand years. But this explanation has very little support among scientists because it is unlikely that a great storm and a temporary sea-level rise would have coincided seven or eight times in the last 5,000 years.

The only note of caution about correlating marsh subsidence with earthquakes is the absence of evidence of strong shaking of marsh deposits that would be expected during a great earthquake.

The most recent great coastal subsidence event occurred 300 to 400 years ago, as dated by carbon-14, and is known to have inundated many marshes and forests from Grays Harbor in Washington to Alsea Bay in Oregon. Carbon-14 dates from partially submerged archeological sites are consistent with submergence during the most recent event as well as an earlier event 3,100 years ago. However, carbon-14 dates do not permit us to say whether a given subsidence event occurred in one earthquake or in several over a period of 50 years. We could calculate the magnitude of an earthquake rupturing the subduction zone from Grays Harbor to Alsea Bay, but this would be considered as a maximum possible event. Tree-ring dating could increase the time resolution, but only where the subsidence events are recorded by killed trees in lowland forests.

These probable subduction-zone earthquakes have occurred on average every 500 to 600 years, but there is so much variation in recurrence interval over the past 4,000 years that the average recurrence interval has little value in predicting the next earthquake.

Sediment cores from the abyssal sea floor at the foot of the continental slope west of Oregon provide evidence of strong shaking, perhaps related to the abrupt coastal subsidence. Sediments deposited on the continental shelf by major rivers, particularly the Columbia River, were apparently destabilized and sent down the continental slope as a high-density, sediment-charged flow analogous to a snow avalanche, but much larger. The most likely triggering mechanism was a giant earthquake. The cores also recovered deposits of ash from the Mount Mazama eruption that formed Crater Lake about 7,600 calendar years ago. Based on the number of turbidity-current deposits on top of the Mount Mazama ash, the average interval between successive turbidity-current deposits is about 500 to 600 years, with the most recent deposit about 300 years ago. These estimates resemble those for marshland subsidence events, adding support for the origin of both by great earthquakes.

Accurate repeated leveling surveys of Oregon highways provide evidence for deformation in the last 100 years. This leveling study is in its early stages, because the highways were last leveled in 1987, and the data are only partially analyzed. However, there is clear evidence of eastward tilting of the Coast Range toward the Willamette Valley, northward tilting of the coast between southern Oregon and Newport, and southward tilting of the coast between Astoria and Tillamook. We cannot say whether this deformation represents elastic strain accumulation prior to a future earthquake or whether this deformation has nothing to do with earthquakes. This is a profitable line of investigation, however, and future studies may lead to more definitive evidence from geodetic evidence of this kind.

Studies in the Willamette Valley have not yet produced evidence that the Portland Hills fault, Gales Creek fault, Corvallis fault, and other faults in the Valley are active and capable of producing earthquakes. In addition to these faults, there are broad folds in the Tualatin Valley and Portland basin. The faults are not long and throughgoing, as they are in California, but instead are relatively short and offset at right angles by other faults. The faults and folds are consistent with the observed stress field of western Oregon, which is characterized by the maximum compressive stress oriented north-south. These faults and folds clearly deform flows of the Columbia River Basalt Group deposited 16.5 to 12 million years ago. Most of these structures also deform semiconsolidated sediments that overlie Columbia River basalt, but these sediments are poorly dated. If these sediments are as young as a few hundred thousand years, then these faults would be shown to be capable of generating future earthquakes. Investigations to answer these questions are underway.

The only clear evidence for recent crustal earthquakes comes from the South Slough of Coos Bay, where marshes show evidence of at least eight burial events in the last 5,000 years. South Slough is in the axis of a syncline, or down-fold, and the buried marshes show that this syncline was formed by a series of earthquakes, possibly on a deeply buried fault that nowhere reaches the surface. Coos Bay is at the eastern margin of a zone of active faults and folds that extends north-northwestward offshore, parallel to the foot of the continental slope and not parallel to the coastline, which extends northward. These faults and folds respond to the north-eastward subduction of the Juan de Fuca Plate beneath Oregon and are not in accord with the north-south principal compressive stresses measured elsewhere in western Oregon. Thus, we cannot apply the evidence for earthquakes at Coos Bay directly to the Willamette Valley, which is much farther inland from the trench.



Western Oregon has very few instrumentally recorded earthquakes, and most of these are in the Portland area, part of a zone that extends northward into Washington. Part of the reason for so few earthquakes is that Oregon has very few seismographs to record small earthquakes, as compared with adjacent states. For this reason, small earthquakes that could be recorded in Washington or California are not recorded in Oregon. However, the lack of larger earthquakes, magnitude greater than 2.5, is not an artifact of poor instrumentation. The Washington network has recorded many earthquakes in the North American crust and many more in the deep oceanic slab that is now being subducted, but none on the interface between the two plates, the place where subduction-zone earthquakes would occur. The absence of earthquakes could be explained by very smooth, frictionless subduction or by subduction having stopped entirely. Neither explanation is likely. The most logical explanation is that the subduction zone is completely locked and is building up strain for a future earthquake. Most of the San Andreas fault that ruptured in great earthquakes in 1857 and 1906 is seismically quiet, like the Willamette Valley. The Coos Bay region, with the only clear evidence for recent crustal earthquakes, is also seismically quiet. Even so, the complete absence of instrumentally recorded earthquakes on the subduction-zone interface is difficult to explain.

The lack of historical earthquakes should not be taken as evidence for low seismic hazard, because Oregon's recorded history spans less than 200 years, which is not sufficient time to be significant in earthquake-hazard evaluation. The submergence of archeological sites indicates that earthquakes affected Native American communities prior to the establishment of a culture that kept written records. The Armenian earthquake of December 1988 occurred in an area that had not had a major earthquake in 700 years, based on historical records. A large portion of that part of the San Andreas fault of California that ruptured in great earthquakes in 1857 and 1906 is now as seismically quiet as the Willamette Valley. The southern San Andreas fault has not had a major earthquake in several hundred years, and a long-range prediction experiment is now underway in that region.

In conclusion, the marsh evidence is convincing enough to issue a public warning about earthquake hazard in Oregon. We cannot say how large a subduction-zone earthquake could be, nor can we forecast when the next one might occur. We also have not been able to assess the earthquake hazard posed by local earthquake sources beneath the Willamette Valley. We are on the steep part of the learning curve, and there are many challenges ahead of us. □

## The 15 most significant earthquakes in U.S. history

For National Earthquake Awareness Week, April 2-8, 1989, the U.S. Geological Survey (USGS) released a list of the 15 most significant earthquakes in the history of the United States.

Robert Wesson, chief of the Office of Earthquakes, Volcanoes, and Engineering at the USGS National Center in Reston, Virginia, said the basis for selection of the 15 earthquakes is a combination of magnitude, damage, and casualties.

Earthquakes are measured in two basic ways: magnitude and intensity. Magnitude is an instrumental measure of the amount of energy released by an earthquake, as indicated by ground motion. Magnitude scales theoretically have no upper limit. The Modified Mercalli Scale (MMS) of intensity, using Roman numerals, is based on human judgment of the amount of damage and effects caused by earthquakes and ranges from I (not felt) to XII (almost total destruction of human-made structures).

The 15-most significant earthquakes in U.S. history, listed in order of the time of their occurrence, are as follows:

**1. Cape Ann, Massachusetts, November 18, 1755.** Estimated magnitude 6.0, maximum MMS intensity VIII. It was centered in the Atlantic 200 mi east of Cape Ann and was felt over 400,000 mi<sup>2</sup>, from Nova Scotia south to Chesapeake Bay and from Lake George, N.Y., east into the Atlantic. Damage was heaviest on Cape Ann and in Boston, with about 100 chimneys destroyed.

**2. New Madrid, Missouri, seismic zone, 1811-1812.** In the most violent series of earthquakes in U.S. history, three earthquakes (in this list counted as one) hit the New Madrid seismic zone in southeastern Missouri and northeastern Arkansas on December 16, 1811, and January 23 and February 7, 1812, at estimated magnitudes of 8.4 to 8.7 and maximum MMS intensities of XI. Damage and casualties were not great because the area was sparsely populated, but the earthquakes were felt over the entire United States east of the Mississippi River and probably far to the west. The earthquakes caused extensive changes in the surface of the land.

**3. Virgin Islands, November 18, 1867.** Estimated magnitude 7.5, maximum MMS intensity VIII. It was felt from the Dominican Republic to the Leeward Islands. Property damage occurred in the Virgin Islands and Puerto Rico, some caused by 20-ft sea waves triggered by the earthquake.

**4. Charleston, South Carolina, August 31, 1886.** Estimated magnitude 6.6, maximum MMS intensity X. It killed 60 people. Most buildings in the Charleston area were damaged or destroyed, with losses of \$20 million. It was felt in New York City, Boston, Milwaukee, Havana, and Ontario.

**5. Charleston, Missouri, October 31, 1895.** Estimated magnitude 6.2, maximum MMS intensity IX. It was near the junction of the Mississippi and Ohio Rivers and was the strongest shock in the New Madrid seismic zone since the three great earthquakes in 1811-1812. It was felt over 1 million square miles in 23 states and Canada, caused considerable damage, and created a four-acre lake near Charleston.

**6. San Francisco, California, April 18, 1906.** Estimated magnitude 8.3, maximum MMS intensity XI. Although known as the San Francisco earthquake, the 1906 shock actually ruptured the San Andreas fault along a 270-mi-long segment from San Benito County north to Humboldt County. Fault slip was up to 21 ft in Marin County. Damage was estimated at more than \$24 million, directly from the earthquake and from the fires that followed in San Francisco. The death toll from the earthquake and fires was more than 700 persons.

**7. Mona Passage, Puerto Rico, October 11, 1918.** Estimated magnitude 7.5, maximum MMS intensity IX. It was one of the most violent recorded on Puerto Rico and was followed by a tsunami that drowned many people. The death toll was 116, and damage was estimated at \$4 million.

**8. Long Beach, California, March 10, 1933.** Although the magnitude was only 6.2, and the maximum MMS intensity was VIII, this earthquake was one of the most destructive in the United States because it was in a heavily settled area, with many poorly constructed buildings, including schools. About 115 people were killed, and hundreds more were injured. Damage was estimated at \$40 million. The earthquake led to stricter construction codes in California to mitigate earthquake damage.

**9. Olympia, Washington, April 13, 1949.** Magnitude 7.1, maximum MMS intensity VIII. This earthquake caused heavy damage in Washington and Oregon. Eight people were killed, and many others were injured. The earthquake was felt eastward to western Montana and south to Cape Blanco, Oregon.

*(Continued on page 92, Earthquakes)*

# MINERAL EXPLORATION ACTIVITY

## Introduction

This is the first of a new series of columns that will appear in each issue of *Oregon Geology*. Entitled "Mineral Exploration Activity," the column will provide up-to-date information to the public and the mineral industry about current mineral exploration activities in Oregon.

In each column, a table will list the names of exploration sites until they are reclaimed and abandoned or until they start production. Public meetings regarding specific mining projects will also be announced.

Readers who have questions or comments about this new listing should contact Gary Lynch or Allen Throop in the Albany office of the Oregon Department of Geology and Mineral Industries (DOGAMI), phone (503) 967-2039.

## Public hearing

An informational meeting to discuss the Atlas Precious Metals Grassy Mountain project and the roles of the Bureau of Land Management (BLM), DOGAMI, the Department of Environmental Quality, and Malheur County took place on July 6, 1989, in Vale. For details about what happened at the meeting, contact Allen Throop of DOGAMI (see above phone number) or Ralph Heft of the Vale BLM office, phone (503) 473-3144.

## Major metal mining activity

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl

Date	Project name, company	Project location	Metal	Status
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services, Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	QM Chevron Resources Co.	T. 25 S. R. 43 E. Malheur County	Gold	App
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
January 1989	Silver Peak Formosa Exploration, Inc.	T. 31 S. R. 6 W. Douglas County	Copper, zinc	App, com
May 1989	Hope Butte Chevron Resources Co.	T. 17 S. R. 43 E. Malheur County	Gold	App

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. □

## (Earthquakes, continued from page 91)

**10. Hebgen Lake, Montana, August 17, 1959.** Magnitude 7.3, maximum MMS intensity X. The strongest recorded earthquake in Montana was felt over 600,000 mi<sup>2</sup>, from Seattle, Washington, to Banff, Alberta, Canada, to Dickinson, North Dakota, to Provo, Utah. It caused massive waves on Hebgen Lake that did not subside for 12 hours and also caused a large landslide that blocked the Madison River canyon, creating a large lake. At least 28 people were killed, and damage was extensive to summer homes and highways in the region.

**11. Prince William Sound, Alaska, March 27, 1964.** This magnitude-8.4 Good Friday earthquake is the second strongest in the world during the 20th century, topped only by a magnitude-8.6 earthquake in Chile in 1960. The maximum MMS intensity was X. The Alaska earthquake triggered extensive landsliding and generated tsunamis. It caused an estimated \$311 million in damage in Anchorage and south-central Alaska and killed 131 people. As a result of this earthquake and a magnitude-6.5 tremor in the San Fernando Valley of California in 1971, the federal government, mostly through the USGS, greatly expanded its research on earthquakes.

**12. Seattle, Washington, April 29, 1965.** Magnitude 6.5, maximum MMS intensity VIII. This second strongest recorded earthquake

in Washington was felt over 130,000 mi<sup>2</sup> of Washington, Oregon, Idaho, Montana, and British Columbia. Seven people were killed, and damage was estimated at \$12.5 million.

**13. San Fernando, California, February 9, 1971.** Magnitude 6.6, maximum MMS intensity XI. It killed 65 people, injured many others, and caused \$1 billion in damage in the Los Angeles area. As a result of this earthquake and the 1964 Good Friday earthquake in Alaska, the federal government greatly expanded its earthquake research and re-evaluated seismic design for hospitals and other critical facilities.

**14. Coalinga, California, May 2, 1983.** Magnitude 6.7, maximum MMS intensity VIII. It injured 45 people and caused \$31 million in damage, with the worst damage occurring in downtown Coalinga. The earthquake was felt from Los Angeles to Sacramento and from San Francisco to Reno.

**15. Borah Peak, Idaho, October 25, 1983.** Magnitude 7.0, maximum MMS intensity IX. The largest earthquake recorded in Idaho was felt over 330,000 mi<sup>2</sup>. Two children were killed in Challis, Idaho, and damage was estimated at \$12.5 million.

—USGS news release

## Gunnar Bodvarsson dies

Gunnar Bodvarsson, Professor Emeritus of mathematics and geophysics at Oregon State University (OSU), died in Corvallis in May 1989. A member of the OSU College of Oceanography faculty, he specialized in geophysical oceanography. His interests and research projects were far reaching and ranged from fisheries to geothermal and nuclear energy problems.

Born 1916 in Reykjavik, Iceland, Bodvarsson received an engineering degree in Munich, Germany; a mathematics and engineering degree in Berlin; and a doctorate from the California Institute of Technology in Pasadena. He worked as an engineer in Copenhagen and later served as chief engineer with the State Drilling Authority of Iceland and the Geothermal Department of the State Electrical Authority of Iceland. In 1964, he joined the faculty of OSU, where he remained until his retirement in 1984.

Bodvarsson worked as a consultant for the United Nations in several countries in South America, including Mexico, Costa Rica, El Salvador, Guatemala, Nicaragua, and Chile.

Among his honors and awards were the Oregon Academy of Science Award for 1979, the Geothermal Pioneer Award from the Geothermal Resource Council in 1988, and an honorary doctorate from the University of Iceland in 1988.

His survivors include his wife Tove, three children, and one grandson. □

## Glenbrook Nickel facility in Riddle starts production

Cominco Resources International, Ltd., has announced that its wholly owned U.S. subsidiary, Cominco American Resources, Inc., has rehabilitated and is operating the former Hanna Nickel Smelting Company plant near Riddle, Oregon, through Glenbrook Nickel Resources, a joint venture of Cominco American and USA Investments, an investment and realty company based in Bozeman, Montana.

M.A. Hanna Company of Cleveland permanently closed the mine and smelter in January 1987, when nickel prices fell to below \$2 per pound. Nickel Mountain Resources, a subsidiary of Universal Consolidated Companies of Fremont, Ohio, purchased the assets of the mine and smelter from Hanna in October 1987 and currently has a lease-purchase arrangement with Glenbrook Nickel Resources.

The companies have been evaluating the possibilities of processing a stockpile of 6 million tons of lateritic nickel ore, grading at 0.7 percent nickel, that was left at the site by Hanna when the drop in nickel prices made it too expensive to process. However, the recovery in nickel prices to as high as \$10.80 a pound in March 1988 and to an average price ranging between \$5 and \$6 a pound in June 1988 has made it feasible to process the stockpile. Glenbrook's plans include starting production of ferrosilicon in June, followed by ferromanganese in July.

Glenbrook hired about 80 people to rehabilitate the smelter complex and eventually plans to employ about 250 people at the plant. □

## AGI/GIS offer new edition of guidebook list

A new, the fifth, edition of the *Union List of Geologic Field Trip Guidebooks of North America* has been compiled and edited by the Guidebooks Committee of the Geoscience Information Society, Charlotte Derksen, Chair, and published by the American Geological Institute (AGI). The more than 6,500 field-trip guidebooks listed in this 223-page volume were written for field trips held between 1891 and the end of 1985. The *Union List* is now available for the

price of \$60 from Customer Service, AGI, 4220 King Street, Alexandria, VA 22302. Credit-card orders may be placed by phone to (800) 336-4764.

The main part of the *Union List* is arranged by organizations that hold meetings or conferences. Under each organization, its meetings and the guidebooks issued at these meetings are arranged chronologically.

The individual field-trip guide citation includes information about which libraries have copies and what the lending policies of those libraries are. More than 200 libraries in Canada and the United States have contributed to this edition.

The main part of the list is followed by a geographic index and, for the first time in the publication history of the *Union List*, a stratigraphic index.

It is often difficult to obtain guidebooks for the field trips held at geology meetings every year. Few are available for purchase after the field trips have taken place. Many field-trip guidebooks are not announced in publishers' lists, even though such guidebooks can be significant sources of local geology information. Sometimes interlibrary borrowing of a guidebook may be the only way for someone to obtain a copy. The *Union List* is intended to alleviate this situation, both as a bibliography and as a finding tool. □

## Changes in DOGAMI publication sales announced

The publication sales section of the Oregon Department of Geology and Mineral Industries (DOGAMI) has announced some changes in its publication sales.

### Available publications

The *Geologic map of Oregon east of the 121st meridian*, Map I-902 published by the U.S. Geological Survey (USGS), is now out of print and will not be reprinted. A new, single-sheet geologic map for the entire state is currently in preparation and expected to become available in 1990. In the meantime, DOGAMI will offer blackline copies of Map I-902 along with photocopies of the legend.

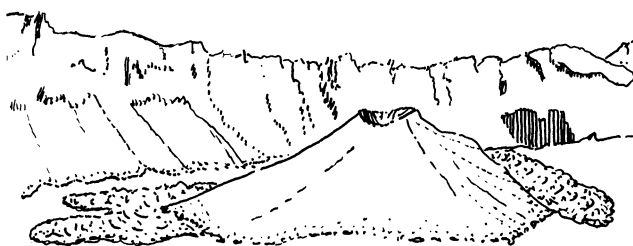
DOGAMI now carries the available maps of the USGS series of 1:100,000-scale (30- by 60-minute) topographic maps, which sell for \$4 and have turned out to be quite popular. Maps for about half the state are available now, and DOGAMI will add the new ones as they are issued.

The USGS 1:1,000,000-scale base map for the entire state is also newly offered (\$4).

The special packets on minerals and counties are currently being reorganized and updated and will not be available for a while.

### Ordering convenience

Orders for publications will now be accepted via mail, phone or Fax (503-229-5639), if they are charged to Mastercard or Visa. No minimum amount of the order is required for this service, but a 10-percent handling fee will be charged for orders taken over the phone. As before, orders are still mailed with no additional charge for postage. □



Position Announcement  
Oregon Department of Geology and Mineral Industries

**Marine minerals coordinator**

Full-time permanent position, available October 1, 1989. Starting salary approximately \$2,200-\$2,500 per month plus generous fringe. Location is Portland, Oregon.

Graduate degree and marine minerals experience are required, as well as a minimum of four years of progressively responsible experience in acquisition, evaluation, interpretation, and management of marine technical and/or economic data. The successful candidate will provide marine mineral resource input to a multidisciplinary offshore State planning effort for the Oregon coast and offshore area.

Duties will include management of the Department's marine minerals program, negotiating and administering contracts for offshore studies, planning and conducting meetings and symposia, writing and presenting clear and concise reports and publications, and participating in the geologic aspects of coastal land use planning and offshore resource planning. This position also requires effective communication with a diverse public, providing the public service role for the Department on offshore issues and serving on offshore planning committees. Close coordination with the public; local government; and Federal, State, university, and industry counterparts is required.

Interested applicants should send resumes and three references, including name and phone number, from present and previous supervisors, as well as requests for the necessary application packet to the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528, phone (503) 229-5580. Deadline for receipt of completed application packet is September 1, 1989.

An equal opportunity employer.

*(Fossils, continued from page 86)*

A spokesman for the Portland, Oregon, BLM office stated, "There is a prohibition against collecting vertebrate fossils except for scientific purposes. A permit is required from the surface management agency. On BLM lands, there is a limit of 25 pounds plus one piece per day for petrified wood collection, with an annual limit of 250 pounds per person. Collection of small, noncommercial quantities of hobby materials is allowed free of charge. Gathering or collecting for the purpose of sale or barter is prohibited unless especially authorized. Collection on recorded mining claims is not advised without the mining claimant's consent because of legal problems that might arise between the claimant and the collector."

USFS regulations prohibit excavating, damaging, or removing any vertebrate fossil or removing any paleontological resource for commercial purposes without a special-use permit.

If you have any questions about whether you may collect at a specific site, be sure you contact the local office of the appropriate federal agency if you are on federal land, the appropriate state agency if you are on state land, and the property owner if you are on private property.

**LAY DOWN THE MAGAZINE, GRAB YOUR ROCK HAMMER, AND GO!**

If you know of a spot where fossils are found and may be collected, you are ready to start. If not, hit the nearest library to get a clue, and then make a try. You are sure to enjoy your experience. As with other adventures, getting off and running may be a bit confusing, but remember, "The longest of journeys begins with but one

## ABSTRACT

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

**GEOLOGIC, STRUCTURAL, AND GEOCHEMICAL FEATURES OF BASALTIC AND RHYOLITIC VOLCANIC ROCKS OF THE SMITH ROCK/GRAY BUTTE AREA, CENTRAL OREGON**, by Walter A. Obermiller (M.S., University of Oregon, 1987), 189 p.

Rocks of the Smith Rock/Gray Butte area reflect Tertiary bimodal volcanic activity in central Oregon. Ages of the units, formerly thought to be Eocene-Oligocene, were estimated by means of leaf fossils and new K-Ar ages obtained in this study and were found to span the range of approximately 36 to 10 m.y. The Smith Rock tuff and the Gray Butte rhyolite were determined to be Miocene in age. Abundances of major, minor, and trace elements were determined for basalts and rhyolitic rocks of the study.

Basaltic rocks, which include subordinate olivine-phyric tholeiites and aphyric basaltic andesites, feature large TiO<sub>2</sub> abundances, as they are characteristic for extensional environments. The most important petrogenetic process for the basalts is fractional crystallization. Mass-balance calculations in conjunction with trace-element models confirm this model.

Rhyolites and ash-flow tuffs exhibit typical recrystallization textures, and their major-element compositional features are believed to have changed. They are mostly corundum normative. Other notable features of the rhyolites include negative Eu anomalies and large Ni and Hf abundances similar to those in Icelandic rhyolites. Nd- and Pb-isotope ratios suggest crustal involvement in the petrogenesis of both basalts and rhyolites. Crystal fractionation models to derive rhyolites from contemporaneous basaltic andesites fail to produce the enrichment of trace elements observed in the rhyolites. Trace-element models involving partial melting (approximately 14 percent) of basaltic andesite to produce rhyolites are capable of explaining the observed trace-element enrichments but cannot be supported by a major-element model, because the compositions of feldspars are expected to change unpredictably during partial melting. □

step." Have fun. Before long, you will be looking for room to house your collection and will be proudly showing it to the public. Just be sure none of your finds ends up as a clock on a study wall for lack of identification marking.

### ACKNOWLEDGMENTS

The author thanks reviewers William N. Orr, Steven R. Manchester, David G. Taylor, and Theodore Fremd for their suggestions and contributions of photographs.

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## AVAILABLE DEPARTMENT PUBLICATIONS

### GEOLOGICAL MAP SERIES

	Price	No. copies	Amount
GMS-5. Geologic map, Powers 15-minute quadrangle, Coos and Curry Counties. 1971	3.00		
GMS-6. Preliminary report on geology of part of Snake River canyon. 1974	6.50		
GMS-8. Complete Bouguer gravity anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-9. Total-field aeromagnetic anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-10. Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	3.00		
GMS-12. Geologic map of the Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	3.00		
GMS-13. Geologic map, Huntington and part of Olds Ferry 15-min. quadrangles, Baker and Malheur Counties. 1979	3.00		
GMS-14. Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00		
GMS-15. Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	3.00		
GMS-16. Free-air gravity anomaly map and complete Bouguer gravity anomaly map, south Cascades, Oregon. 1981	3.00		
GMS-17. Total-field aeromagnetic anomaly map, south Cascades, Oregon. 1981	3.00		
GMS-18. Geology of Rickreall, Salem West, Monmouth, and Sidney 7½-min. quads., Marion/Polk Counties. 1981	5.00		
GMS-19. Geology and gold deposits map, Bourne 7½-minute quadrangle, Baker County. 1982	5.00		
GMS-20. Map showing geology and geothermal resources, southern half, Burns 15-min. quad., Harney County. 1982	5.00		
GMS-21. Geology and geothermal resources map, Vale East 7½-minute quadrangle, Malheur County. 1982	5.00		
GMS-22. Geology and mineral resources map, Mount Ireland 7½-minute quadrangle, Baker/Grant Counties. 1982	5.00		
GMS-23. Geologic map, Sheridan 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-24. Geologic map, Grand Ronde 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-25. Geology and gold deposits map, Granite 7½-minute quadrangle, Grant County. 1982	5.00		
GMS-26. Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00		
GMS-27. Geologic and neotectonic evaluation of north-central Oregon. The Dalles 1°x2° quadrangle. 1982	6.00		
GMS-28. Geology and gold deposits map, Greenhorn 7½-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-29. Geology and gold deposits map, NE¼ Bates 15-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-30. Geologic map, SE¼ Pearsoll Peak 15-minute quadrangle, Curry/Josephine Counties. 1984	6.00		
GMS-31. Geology and gold deposits map, NW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-32. Geologic map, Wilhoit 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-33. Geologic map, Scotts Mills 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-34. Geologic map, Stayton NE 7½-minute quadrangle, Marion County. 1984	4.00		
GMS-35. Geology and gold deposits map, SW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-36. Mineral resources map of Oregon. 1984	8.00		
GMS-37. Mineral resources map, offshore Oregon. 1985	6.00		
GMS-38. Geologic map, NW¼ Cave Junction 15-minute quadrangle, Josephine County. 1986	6.00		
GMS-39. Geologic bibliography and index maps, ocean floor and continental margin off Oregon. 1986	5.00		
GMS-40. Total-field aeromagnetic anomaly maps, Cascade Mountain Range, northern Oregon. 1985	4.00		
GMS-41. Geology and mineral resources map, Elkhorn Peak 7½-minute quadrangle, Baker County. 1987	6.00		
GMS-42. Geologic map, ocean floor off Oregon and adjacent continental margin. 1986	8.00		
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VOLUME 51, NUMBER 5

SEPTEMBER 1989

**THE GREAT GRANT COUNTY FIREBALL**  
*Also in this issue:*  
**EVALUATING EARTHQUAKE HAZARDS IN THE PORTLAND AREA**  
**GEOTHERMAL EXPLORATION IN OREGON, 1988**

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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 DOGAMI.

## COVER PHOTO

On October 23, 1987, Oregon experienced the largest fireball ever reported in the state during this century. Picture shows "smoke" cloud as seen from Mount Vernon, Grant County, 50 seconds after the sonic boom, 26 km from the fireball's end point. Photo by Mike Burgett. See related article on page 111.

## DOGAMI announces contest for best nontechnical geologic paper

The Oregon Department of Geology and Mineral Industries (DOGAMI) would like for Oregonians and visitors to enjoy more fully the geology of the state. We are announcing a contest for the best nontechnical paper or field trip guide on the geology of the state. The winning papers and possibly some of the runners-up will be printed in *Oregon Geology*. The rules are as follows:

1. The contest is open to anyone knowledgeable about the geology of Oregon except for DOGAMI employees or their families.

2. The subject is some aspect of the geology of the state. Articles or field trip guides are welcome. The paper should be nontechnical and written for the interested lay public, not just for other geologists. Papers should be technically correct and should contain up-to-date information. They will be judged on their readability, interest to the nongeologist, and quality and accuracy of information.

3. The papers should not exceed 15 pages of *Oregon Geology*, including maps, figures, and photos. One typeset page of the magazine with no pictures contains between 1,300 and 1,400 words.

4. Manuscripts should be typed double spaced, and three copies should be submitted. The author's name should not be on the manuscript but should be placed with address, phone number, and title of article on a separate sheet of paper inside the envelope with the manuscript. All artwork should be camera-ready. Only black-and-white photographs can be used.

5. All material should use DOGAMI format, which is similar to that used by the U.S. Geological Survey (USGS). Consult recent issues of *Oregon Geology* or the USGS *Suggestions to Authors* (6th ed.) for specific questions.

6. All entries should be mailed to Beverly F. Vogt, Publications Manager, DOGAMI, 910 State Office Building, Portland, OR 97201, and must be received no later than January 31, 1990. DOGAMI is not responsible for entries lost in the mail. Manuscripts will be returned upon request.

7. Entries will be judged by a panel of three judges. Winners will be announced in the May 1990 issue of *Oregon Geology*. The first prize is \$500. Second prize is \$300. Third prize is \$150. If no suitable manuscripts are entered, no prizes will be awarded. DOGAMI reserves the right to publish manuscripts in *Oregon Geology*.

8. Questions should be addressed to Beverly Vogt at DOGAMI. □

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# Geothermal exploration in Oregon, 1988

by George R. Priest and Gerald L. Black, Oregon Department of Geology and Mineral Industries

## LEVEL OF GEOTHERMAL EXPLORATION

### Introduction

Aside from a few shallow temperature-gradient holes drilled by the U.S. Geological Survey (USGS) in the Western Cascades, no significant geothermal exploration occurred in 1988. The amount of leased land declined on both U.S. Bureau of Land Management (USBLM) and USDA Forest Service (USFS) lands. The total amount of federal land leased for geothermal resources has declined annually by small amounts since the peak in 1983.

### Drilling activity

Figure 1 shows the number of geothermal wells drilled and geothermal drilling permits issued from 1970-1988. Figure 2 shows the same information for geothermal prospect wells (depths < 610 m). Tables 1 and 2 list the Oregon Department of Geology and Mineral Industries (DOGAMI) permits for geothermal drilling that were active in 1988. Five new permits were issued, three for prospect holes and two for geothermal wells. Only four holes were drilled. All were shallow (< 152 m) temperature-gradient holes drilled by the USGS in the northern part of the Western Cascades.

### Leasing

The consolidation of land holdings continued in 1988 as the total leased acreage of federal lands decreased by about 10 percent (Table 3; Figure 3). This decrease in leased lands was the result of a 53-percent decline in USBLM leases coupled with a 6-percent decrease in USFS leases (Table 3). This decrease marks the fifth

straight year of decline since the 1983 peak in total leased acreage.

There are 112 leases pending on Forest Service lands in Oregon. Of these leases, 57 are awaiting preparation of Environmental Assessments or Environmental Impact Statements. The remainder are awaiting reports on adverse effects regarding the National Park Service (NPS). There are no leases pending on USBLM lands in Oregon.

Figure 4 is a graph of the annual total monies received by the federal government from geothermal leasing in Oregon from 1974, when leasing was initiated, to the present. Included in the graph is income from filing fees, rental on competitive and noncompetitive leases, and bonus bids. Income from geothermal leasing peaked in 1980 at \$1,701,189 and has declined steadily since then to its present level of about \$435,000.

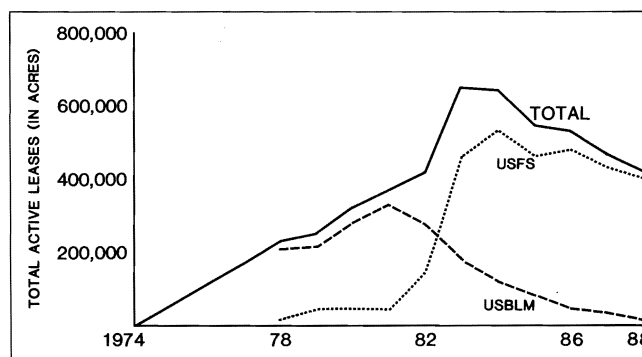


Figure 3. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December 1988.

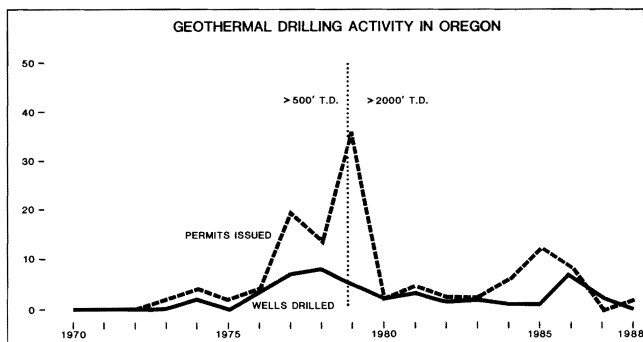


Figure 1. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 610 m.

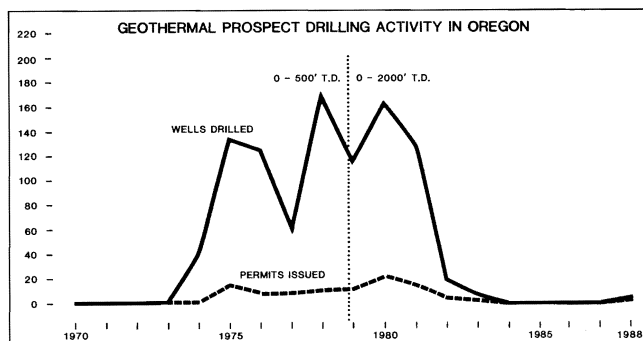


Figure 2. Geothermal prospect-well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth of less than 610 m.

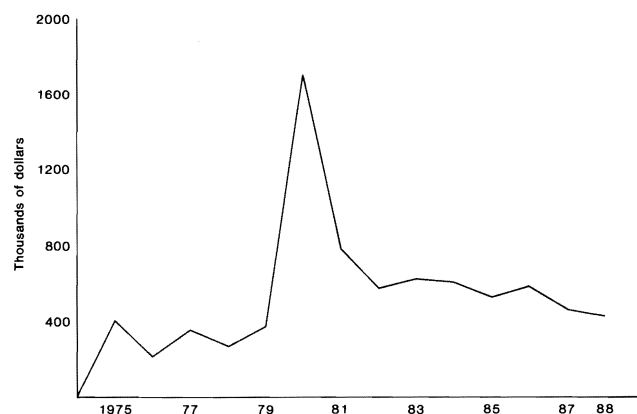


Figure 4. Federal income from geothermal leases in Oregon from the inception of leasing in 1974 to the present.

### KNOWN GEOTHERMAL RESOURCE AREA (KGRA) SALES

No KGRA lands were offered for bid in 1988. Some KGRA lands at Newberry volcano will probably be incorporated into a proposed geological monument (see section on regulatory actions).

### REGULATORY ACTIONS

In May 1988, Congress ordered the Secretary of the Interior to determine whether or not significant thermal features exist in Crater Lake National Park. The Secretary was required to report within six months (see section on the Mount Mazama area for further information).

Table 1. *Active permits for geothermal drilling in 1988*

Permit no.	Operator, well API number	Location	Status, proposed total depth (m)
116	Calif. Energy Co. MZI-11A 035-90014	SW ¼ sec. 10 T. 31 S., R. 7 ½ E. Klamath County	Suspended; 413.
117	Calif. Energy Co. MZII-1 035-90015	SE ¼ sec. 13 T. 32 S., R. 6 E. Klamath County	Suspended; 148.
118	GEO* N-1 36-017-90013	SW ¼ sec. 25 T. 22 S., R. 12 E. Deschutes County	Suspended; 1,387.
124	Thermal Power Co. CTGH-1 36-047-90002	SE ¼ sec. 28 T. 8 S., R. 8 W. Marion County	Suspended; 1,463.
125	GEO* N-2 36-017-90018	SW ¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Suspended; confidential.
126	GEO* N-3 36-017-90019	NE ¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Suspended; 1,219.
127	Calif. Energy Co. CE-NB-4 36-017-90020	NW ¼ sec. 16 T. 22 S., R. 13 E. Deschutes County	Plugged and abandoned.
129	Calif. Energy Co. CE-NB-4 36-017-90022	SE ¼ sec. 4 T. 21 S., R. 12 E. Deschutes County	Plugged and abandoned.
131	GEO* N-4 36-017-90023	NE ¼ sec. 35 T. 21 S., R. 13 E. Deschutes County	Suspended; confidential.
132	GEO* N-5 36-017-90024	NE ¼ sec. 8 T. 22 S., R. 12 E. Deschutes County	Suspended; confidential.
135	GEO* NC88-29 36-017-90027	SE ¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Not drilled.
136	GEO* NC54-5 36-017-90028	NE ¼ sec. 5 T. 22 S., R. 12 E. Deschutes County	Not drilled.

\* GEO-Newberry Crater, Inc.

USBLM announced on October 17, 1988, that no adverse effect will occur to any significant thermal feature of Crater Lake National Park resulting from leases issued for acreage 70-160 km north of the Park.

Two temperature-gradient holes drilled in 1986 by California Energy Company, Inc. (CECI), near Crater Lake National Park can now be completed, according to a recent decision by the Interior Board of Land Appeals (IBLA). On February 1, 1989, the IBLA turned down a 1988 appeal by the Sierra Club and other environmental groups that questioned USBLM's decision to approve amendments to the CECI drilling permits. The amendments authorize CECI

to drill to 1,676 m, with loss of circulation of drilling fluid to the subsurface (see the section on the Mount Mazama area for further information).

Anadarko Petroleum Corporation has yet to obtain permission to drill a proposed 457-m test well in the Alvord Desert area (Table 1). Before the permit is approved, USBLM must determine whether the project might endanger rare fish in nearby Borax Lake. The proposed well would test flow rate and flow temperature of the hydrothermal system. Studies are reportedly underway to determine environmental impacts.

USFS and USBLM officials met with industry and environmental groups in February 1989 to work out a preliminary boundary for a proposed geological monument at Newberry volcano. The area of the monument will reportedly encompass much of the land formerly classified as KGRA. The work was still in progress at the writing of this paper.

The Geothermal Advisory Committee in Klamath Falls is considering engineering and financial alternatives that will help users to comply with the Klamath Falls Geothermal Code. The Code requires that users who discharge effluent to the surface must, by 1990, reinject the fluid.

## DIRECT-USE PROJECTS

The direct use of relatively low-temperature geothermal fluids continued in 1988 at about the same level as over the last several years. Most of the activity is centered in Klamath Falls and Vale.

### Ashland

Jackson Hot Springs in Ashland, Oregon, is still being run as a resort.

### Klamath Falls

The Oregon Institute of Technology (OIT) improved its geothermal heating system, and the City continued to wrestle with the problem of defective piping installed in its district heating system. Improvements in the OIT system resulted in a 27-percent reduction in the amount of geothermal water used (Geo-Heat Center Quarterly Bulletin, 1989). An injection well was also drilled at OIT, but more work will have to be done to achieve an adequate level of reinjection (Paul Lienau and Susan Hartford, personal communication, 1989). In 1988, the City completed engineering plans for the replacement of defective pipe connections in part of its system. Replacement should occur in the near future now that legal action has secured \$685,000 from the companies that manufactured and installed the pipe (Geo-Heat Center Quarterly Bulletin, 1989). Further expansion of the system utilizing the Small-Scale Energy Loan Program of the Oregon Department of Energy is planned (Geo-Heat Center Quarterly Bulletin, 1989).

Table 2. *Active permits for geothermal prospect drilling in 1988 (holes less than 610 m)*

Permit no.	Operator, well name	Location	Issue date; status
95	USGS	Mount Hood National Forest	June 1988; drilled two of four sites to 70 and 153 m.
96	USGS	Willamette National Forest	June 1988; drilled two sites to 47 and 91 m.
97	Anadarko Petroleum Corporation Well 25-22A	Alvord Desert area	September 1988; location, one hole.

## La Grande

The Hot Lake Recreational Vehicle Resort plans to utilize 85 °C water from the Hot Lake artesian well to heat a pool later this year. The company hopes to eventually use the resource to heat greenhouses.

## Lakeview

In Lakeview, the binary-cycle electrical generating station set up several years ago remains idle. The 300-kilowatt (kw) unit had an output of 250 kw from 105 °C water in a November 18, 1982, test (Geo-Heat Center Quarterly Bulletin, 1982).

The City of Lakeview terminated its agreement with Brown, Vence, and Associates, the firm that in 1985 won a geothermal franchise in the City. The City is still interested in the development of a district heating system.

## Paisley

The Paisley area has one of the best quality but least utilized low-temperature geothermal resources in the state. Thermal wells there reportedly have high flow rates (observations of Gerald L. Black, 1981) and temperatures as high as 111 °C at only 228 m (Peterson and others, 1982). A campground and recreational vehicle park utilizes hot water for a pool, but no other uses are known.

## Vale

In Vale, the successful Oregon Trail Mushroom Company, which commenced full-scale operations in 1986, continues to operate using water from a 107 °C aquifer for heating and cooling. Oregon Trail annually produces 2.3 million kilograms of mushrooms, which are marketed in Spokane, Seattle, Salt Lake City, and the Treasure Valley area in Idaho (Geo-Heat Center Quarterly Bulletin, 1987). Other users at Vale include Ag-Dryers (a grain-drying facility) and a greenhouse operation.

## Ground-water heat pumps

In the Bend, Redmond, Prineville, and Madras areas of central Oregon and in the Willamette Valley, there was considerable activity in 1988 in the installation of ground-water heat pumps. The Oregon Department of Energy (ODOE) certified 97 residential geothermal tax credits in 1988, most of them for the installation of such systems. At the present time, a tax credit of up to \$1,500 is available for each residence. The amount of tax credit is based on energy savings, not the cost of the system.

## DOGAMI APPLIED RESEARCH

In 1986, DOGAMI received a grant from the U.S. Department of Energy (USDOE) to complete a geologic and geothermal-resource study of the Breitenbush-Austin Hot Springs hydrothermal area, including a detailed analysis of the Thermal Power drill hole, CTGH-1. The CTGH-1 hole was drilled to 1.46-km depth in the High Cascade Range northwest of Mount Jefferson in 1986 (Figure 5). David Sherrod of the U.S. Geological Survey (USGS) cooperated with DOGAMI to edit an open-file report summarizing data from the drill hole and from the Austin-Breitenbush geothermal area in general. The report, Open-File Report O-88-5, entitled *Geology and Geothermal Resources of the Breitenbush-Austin Hot Springs Area, Clackamas and Marion Counties, Oregon*, is available from DOGAMI. The report discusses two possible models of the geothermal system, utilizing all geological, geophysical, geochemical, and hydrological data from the area. Both models require a deep magmatic heat source to explain heat flow in the area, but one model requires that the magmatic heat source be significantly wider than the High Cascades (Blackwell and others, 1982; Blackwell and Baker, 1988), whereas the other model requires a narrow heat source or sources centered under the High Cascades (Sherrod, 1988; Ingebritsen and others, 1989). The latter model produces the observed high regional heat flow in the Western Cascades by lateral

Table 3. *Geothermal leases in Oregon in 1988*

Types of leases	Numbers	Acres
Federal leases in effect:		
Noncompetitive, USFS	223	402,037.95
Noncompetitive, USBLM	2	942.79
KGRA, USFS	1	100.00
KGRA, USBLM	7	16,465.12
Total leases issued:		
Noncompetitive, USFS	344	664,645.18
Noncompetitive, USBLM	266	406,157.79
Total leases relinquished:		
Noncompetitive, USFS	121	262,607.23
Noncompetitive, USBLM	264	405,215.00
KGRA, USFS	7	11,824.61
KGRA, USBLM	55	101,842.73
Lease applications pending	112	—

flow of heated ground water. These models were the subject of heated debate in a December 1988 symposium on the Cascades (see USGS activities).

DOGAMI formulated a scientific drilling program in 1987 (Priest and others, 1987) and had planned to drill a 650-m diamond-core hole in the Santiam Pass area in 1988. The project is now planned for the summer of 1989, because of delayed funding. DOGAMI is evaluating four potential sites (Figure 6). A diamond-core hole 600-1,000 m in depth is planned, with total depth depending on the level of support secured. Those interested in participating in the project are encouraged to contact George R. Priest for further information.

Core from four temperature-gradient holes was donated to DOGAMI by UNOCAL. The holes, drilled in the High Cascades near the South Sister and Mount Jefferson (Figure 5), reached depths ranging from 250 to 610 m. No temperature data are publicly available from the holes, but detailed lithologic logs are being produced as part of DOGAMI's scientific drilling program. The core is stored at Oregon State University, with representative samples available for inspection at DOGAMI.

A synthesis of Cascade geology in central Oregon was presented in 1988 at a symposium on the Cascades sponsored by the USGS (Priest, 1989; see next section). The paper presents a geological cross section through the Three Fingered Jack area that shows in excess of 1 km of downward displacement on a complex graben structure. This amount of displacement is consistent with earlier interpretations of Taylor (1981) and preliminary data from the previously mentioned UNOCAL holes (Smith and others, 1989; Gerald L. Black and Platt Bradbury, unpublished data). High permeability and geothermal fluids could occur in fractures and intergranular pore spaces associated with intra-graben faults and fill.

## USGS ACTIVITIES

The USGS was involved in several geothermal-related projects in 1988. They also performed a great service to the geothermal and geologic communities by organizing and coordinating efforts to publish new research papers on Newberry volcano and the Cascade Range.

David V. Fitterman of the USGS edited a special issue of the *Journal of Geophysical Research* (JGR) on Newberry volcano (JGR, v. 93, no. B9, 1988). The issue includes articles on geology, hydrology, hydrothermal alteration, transient electromagnetic soundings, magnetotellurics, resistivity, high-resolution seismic imaging, gravity, and magnetics (see section on Newberry volcano for details).

In December 1988, the USGS sponsored a Red Book conference on the Geological, Geophysical, and Tectonic Setting of the Cascade Range. Thirty-six new papers on the Cascades were presented at the four-day conference. The papers will be published as a USGS open-file report (Muffler and others, 1989). Many of the papers will appear in a special issue of JGR to be published in 1990.

Much debate on the previously mentioned geothermal models for the Cascades occurred at the Red Book conference (see section on DOGAMI activities), and some actions for resolving the debate were proposed. Cleaning out and logging the 2.5-km-deep Sunedco 58-28 hole near Breitenbush Hot Springs was considered a cost-effective means of definitively testing the two competing models. Drilling additional temperature-gradient holes in the High Cascades was also recommended as a means of establishing how much heat is actually available for lateral transfer to the Western Cascades. Additional heat-flow measurements in the Western Cascades would help to test for complex patterns of heat-flow variation that would be produced by lateral flow of heated ground water.

The USGS Water Resources Division (WRD) completed three years of intensive work in the Cascade Range. The program included NaCl surveys, stable-isotope studies, water chemistry, and temperature-gradient work in the central Oregon Cascades between Mount Hood and the Three Sisters. The data are summarized in

an open-file report (Ingebritsen and others, 1988) and an interpretive paper (Ingebritsen and others, 1989).

WRD also drilled four shallow (47-153 m) temperature-gradient holes in the Western Cascades in 1988 (Table 2); three provided useful temperature gradients (Figures 5 and 7). The holes were drilled to fill in gaps in the existing heat-flow data base. The temperature gradients (51-66 °C/km; Figure 7) are similar to those previously measured by DOGAMI in nearby areas (e.g., Black and others, 1983).

Compilations of the geologic map of the State of Oregon by George W. Walker and Norman S. MacLeod and the Salem 1° by 2° sheet (Walker and Duncan, 1988) were completed. The geologic map of the state will be printed in 1990 or 1991.

David Sherrod and Jim Smith finished a geologic map of the Cascade Range in Oregon (Sherrod and Smith, 1989). The 1:500,000-scale map shows Quaternary volcanic rocks split into five age divisions and four compositional divisions. Western Cascades rocks, which are not as well known as the younger rocks, are shown in lesser detail.

Terry Keith and Keith Bargar continued their hydrothermal-alteration studies of holes drilled under the USDOE cost-share program. They also contributed hydrothermal-alteration studies to the Breitenbush-Austin geothermal report (see section on DOGAMI activities).

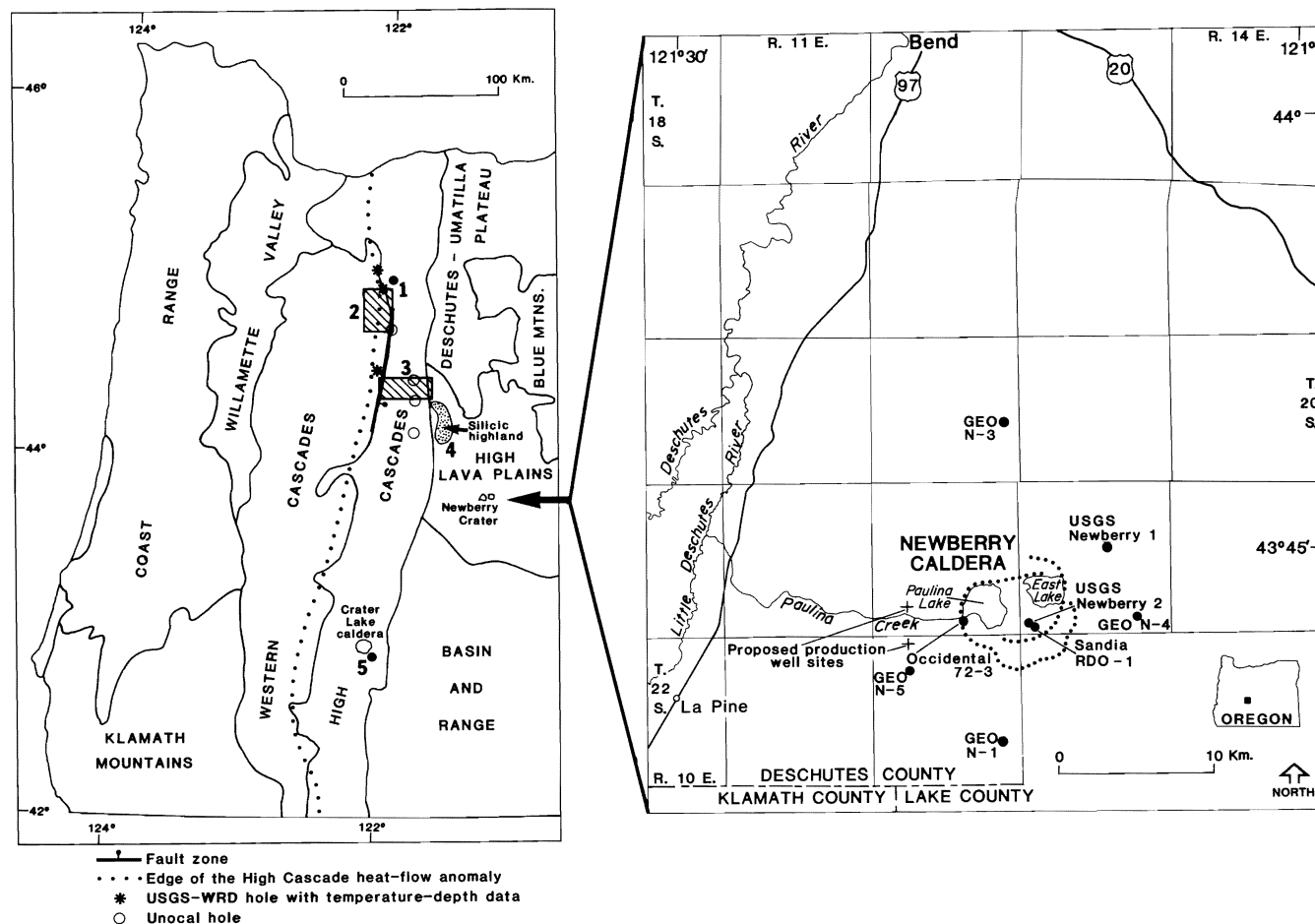


Figure 5. Physiographic provinces of western Oregon (after Dicken, 1950), showing major areas of geothermal activity discussed in text. 1. Location of Thermal Power drill hole CTGH-1. 2. Breitenbush River map area. 3. Santiam Pass study area. 4. Silicic highland. 5. Location of CECI drill hole MZI-11A. Edge of High Cascade heat-flow anomaly after Black and others (1983).

Inset map of Newberry caldera shows locations of temperature-gradient holes discussed in text and GEO permitted production well sites. Dotted lines show ring fractures of Newberry caldera.



Charles Bacon continued his investigation into the volcanic evolution of Mount Mazama, including the study of samples collected from the bottom of Crater Lake during *Alvin* dives. Manuel Nathenson and Michael Thompson presented an interpretation of water chemistry of Crater Lake at the January 1988 Corvallis meeting of the American Association for the Advancement of Science (AAAS).

William Scott and Cynthia Gardner completed their geologic map of the Mount Bachelor area (Scott and Gardner, 1989). The map will be published in color at a scale of 1:50,000.

## **GEO-HEAT CENTER, OREGON INSTITUTE OF TECHNOLOGY**

The Geo-Heat Center at the Oregon Institute of Technology (OIT) specializes in assisting in the development of low-temperature (<90 °C) and moderate-temperature (90-150 °C) geothermal applications for direct use. The Center is under contract with USDOE to provide geothermal services to state and federal agencies who receive requests from engineering consultants, planners, and developers for development assistance on direct-use projects. The assistance can range from answering technical questions and simple consultations on methods, equipment, and applications to providing feasibility studies. The Geo-Heat Center has published over 70 such feasibility studies, which are available as examples. The project period is slated to run through the end of 1992.

The Geo-Heat Center completed a report on geothermal direct use that summarizes applications, regulations, and environmental factors. The report, entitled *Geothermal Direct Use Engineering and Design Guidebook*, is now available (Geo-Heat Center, Oregon Institute of Technology, Klamath Falls, Oregon 97601; phone 503-882-6321).

In 1988, the Geo-Heat Center assembled information on the original design and subsequent performance of a selected group of geothermal district heating systems that have operated at least three years. Specific areas of investigation were (1) customer connect time and disposal and (2) equipment type and materials of construction for production pumps and transmission piping. The operational performance of equipment in each of these areas is described and will serve as a reference for designers of new systems and operators of existing systems. The report will be available from the Geo-Heat Center some time in 1989.

The Geo-Heat Center evaluated downhole heat exchanger performance world wide. A summary of this study should be available sometime in 1989.

The Geo-Heat Center aided OIT in making plans to drill an injection well to eliminate surface discharge from its geothermal system.

The Geo-Heat Center continues to be involved in the evaluation of the Klamath Falls geothermal aquifer. Its staff plays an active role on the Klamath Falls Geothermal Advisory Committee and continues to publish the *Geo-Heat Center Quarterly Bulletin*, which has been in circulation since 1975.

## **ACTIVITIES OF OREGON WATER RESOURCES DEPARTMENT**

The Oregon Water Resources Department (OWRD) continued its low-temperature geothermal program, which includes monitoring of the resources in Vale, the Klamath Falls area, and Lakeview.

The OWRD published a report on the hydrogeology of the developed geothermal aquifer at Vale (Gannett, 1988). The report can be obtained from OWRD.

Monitoring of the geothermal aquifer in Klamath Falls shows that water levels have been declining at a rate of approximately 0.3 m per year since about 1975. In 1985 the City of Klamath Falls passed the Geothermal Management Act in order to eliminate, by 1990, the wasteful geothermal-water discharge that presumably is causing the decline. In November 1987, the Water Resources Commission received a staff report describing the Klamath Falls decline

and its implications. The report recommended that OWRD continue to monitor conditions in the geothermal aquifer and track progress toward the elimination of wasteful discharge. If the decline continues after 1990, OWRD will evaluate the situation and may consider administrative action to stabilize water levels.

Water levels fluctuate seasonally in Klamath Falls, with lowest levels occurring during the peak heating season in February. Water levels in February 1988 did not show any decline relative to 1987, probably due to the mild weather and resultant decreased heating demand.

Users in the Klamath Falls area are continuing to move toward total reinjection of pumped thermal water. The OIT Geo-Heat Center is working on a reinjection well for its system. ReInjection wells are already in use at the city jail and museum.

OWRD now has expanded authority to regulate use of low-temperature geothermal resources. State Senate Bill 237 provides the means for OWRD to protect senior users of a resource by controlling water use when alteration of temperature or undue thermal interference between wells is determined to exist.

## **ACTIVITIES OF ODOE**

In 1988, geothermal activities of the Oregon Department of Energy (ODOE) focused on research and support for other agencies. ODOE, in cooperation with the Washington State Energy Office, continued to perform financial evaluations of new geothermal power plants for the Bonneville Power Administration (BPA).

ODOE responds to inquiries on geothermal energy development from the public. Over 140 such responses were provided in 1988. ODOE also certifies geothermal tax credits: 97 residential and 11 business tax credits (all for heat pump applications) were certified in 1988. ODOE continues to participate in the activities of the Pacific Geothermal Resources Council (GRC), publishing articles at the national meetings and being a board member of the local Northwest Section. Finally, ODOE instructed USFS personnel in geothermal energy in February 1988.

## **RESEARCH BY OSU**

Brittain Hill, a doctoral candidate at Oregon State University (OSU), is continuing his work on Quaternary ash flows in the Bend area (Hill, 1985) and the silicic highland west of Bend. Isotopic age data indicate that the Bend Pumice and Tumalo Tuff, a sequence of air-fall ash-flow deposits, may be considerably younger than previously supposed (Sarna-Wojcicki and others, 1987). Hill has also acquired data that support a silicic highland source for the ash flows (Hill, 1985).

Jack Dymond and Robert Collier of the OSU Oceanography Department continued investigations at Crater Lake during the summer of 1988 (Collier and Dymond, 1988). Their objective is to determine whether or not hot springs exist on the floor of the lake (see section on the Mount Mazama area).

## **RESEARCH BY WASHINGTON STATE UNIVERSITY**

Richard Conrey is finishing up a three-year study of the Mount Jefferson area. He found that, for the last 2.5 m.y., about 200 km<sup>2</sup> of the area has been the site of andesitic to rhyodacitic volcanism (Conrey, 1988). He postulates that a granodiorite-tonalite batholith lies at shallow depths beneath the area.

## **NEWBERRY VOLCANO**

As previously mentioned (section on USGS activities), a special issue of JGR summarized current research on Newberry volcano. Of particular interest is the interpretation by Swanberg and others (1988) that the so-called "rain curtain" effect extends to a depth of about 1,000 m in the 1,219-m GEO N-1 hole (south flank of Newberry volcano). Blackwell and Steele (1987) used the same temperature data to infer that the "rain curtain" effect extends to a depth of only 350-400 m. Black and Priest (1988), in a review of all available

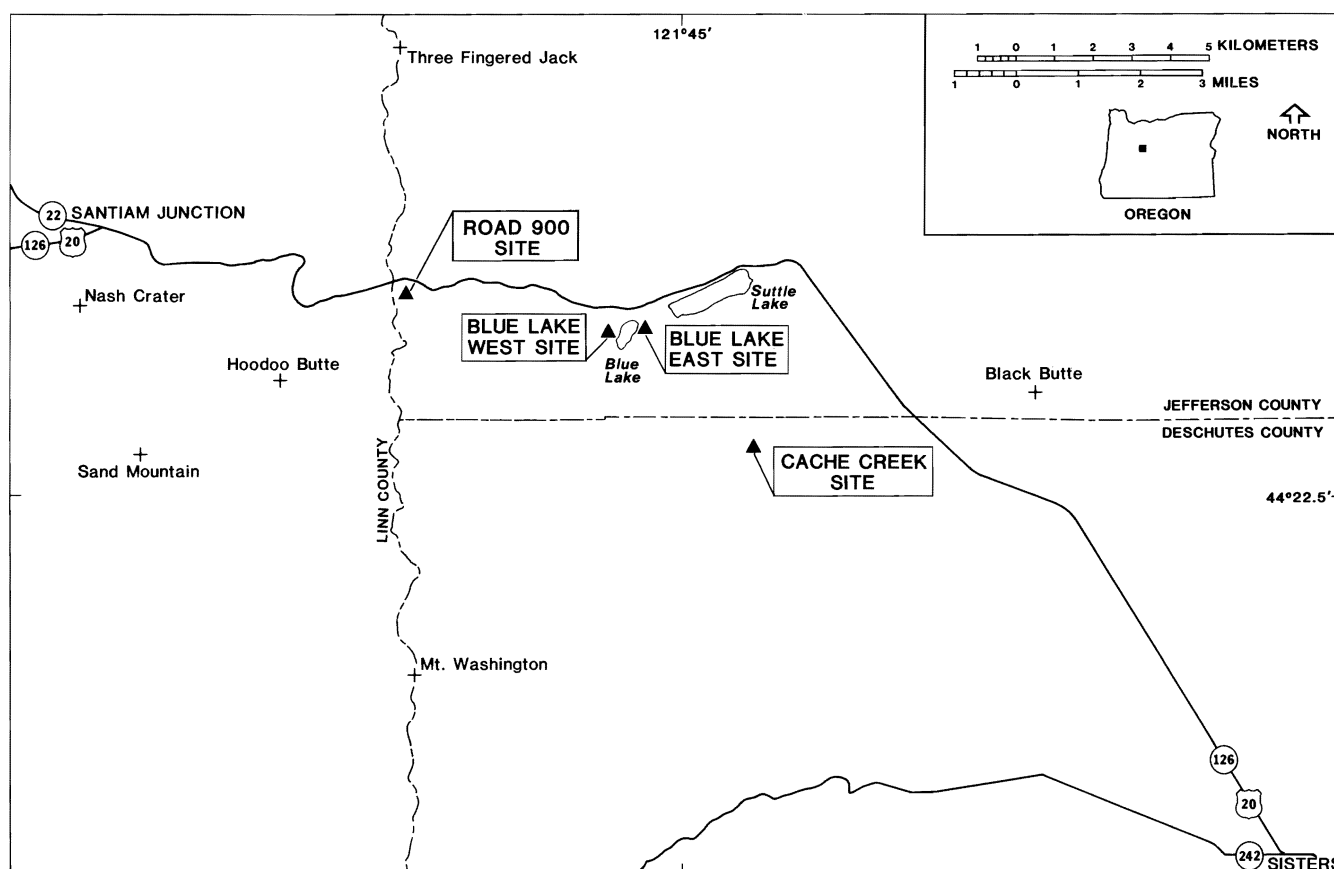


Figure 6. Location of potential scientific drilling sites near Santiam Pass, Oregon.

temperature-depth data at Newberry volcano, concluded that the "rain curtain" extends to a depth of about 450-550 m on the flanks of the volcano. Resolution of this issue is important to those trying to decide on appropriate depths of exploration for temperature-gradient studies of Newberry volcano and other young volcanic areas.

Achauer and others (1988), utilizing high-resolution seismic tomography, identified a low-velocity body at 3 km depth below the summit caldera at Newberry volcano. They interpret the body as "a possible magma chamber a few to a few tens of km<sup>3</sup> in volume."

Sammel and others (1988) presented a theoretical model of the hydrothermal system and concluded that (1) elevated temperature gradients in drill holes on the flanks of the volcano are not influenced by any Holocene magma body under the caldera, and (2) the gradients in the lower part of flank drill holes "may be related to the cumulative effect of older intrusions."

Recently released temperature data from the west flank of the volcano tend to support the hypothesis that a very significant heat source exists there. The period of confidentiality on data from the lower portion of a 1,372-m hole drilled on the west flank of Newberry volcano ended in 1988; the data are therefore now available to the public. The hole was spudded in September 1983 by Occidental Geothermal, Inc., in sec. 3, T. 22 S., R. 12 E. (Figure 5, well 72-3). The hole was drilled to a total depth of 1,068 m in the fall of 1983. The hole was reentered in the fall of 1984 and deepened to 1,372 m. Data from the upper 1,068 m were published in last year's geothermal summary (Black and Priest, 1988). The operator of record is now Santa Fe Geothermal, Inc., of Bakersfield, California. The temperature-depth curve for hole 72-3 is essentially isothermal to a depth of approximately 470 m, reflecting the "rain curtain" effect (Black and Priest, 1988). The temperature gradient from 488 m to 1,366 m is 137 °C/km, with a bottom-hole temperature of 155 °C (Arestad and others, 1988). The gradient is linear, in-

dicating conductive heat flow. Arestad and others (1988) argue that available exploration data favor further exploration of the west flank of the volcano for high-temperature geothermal resources.

Geo-Newberry Crater, Inc., reportedly plans to drill a test well on the west flank of Newberry volcano in 1989. DOGAMI in early 1988 granted permits for two sites: SE ¼ sec. 29, T. 21 S., R. 12 E., and NE ¼ sec. 5, T. 22 S., R. 12 E. (Figure 5). The environmental assessment for the drilling has been approved by USBLM. At this time, it is not known when drilling operations on Newberry will begin.

#### MOUNT MAZAMA AREA (CRATER LAKE AREA)

The reader is referred to Black and Priest (1988) for a detailed history of geothermal development issues at Mount Mazama prior to July 1988.

On June 21, 1988, the Pacific Division of the American Association for the Advancement of Science sponsored a special session on "The Clarity of Crater Lake, Oregon. An Ecosystem Study." A number of papers on the limnology and geohydrology of the lake were given. Sewage and natural processes were discussed as possible sources for the continued degradation of the clarity of the lake.

Responding to the previously mentioned directive from Congress (section on regulatory actions), the National Park Service granted \$225,000 to Jack Dymond and Robert Collier of OSU to study the lake with a number of submarine dives. Temperatures 2-6 °C above the 3.6- °C lake temperature were found in gelatinous bacterial mats on the floor of the lake. These are the highest temperatures measured thus far on the lake bottom. The Park Service convened a panel of experts to review the findings of the OSU team. Additional dives are planned for the summer of 1989 (Jack Dymond, personal communication, 1989).

In 1989, California Energy Company reportedly plans to continue drilling on the Mount Mazama sites permitted by the previously discussed IBLA decision (see section on regulatory actions). In 1986, the MZI-11A site (Table 1) was drilled to 413 m, yielding a bottom-hole temperature of 107 °C and a temperature gradient of 372 °C/km in the lowest 20 m of the hole (Priest and others, 1987).

## ACKNOWLEDGMENTS

We acknowledge the cooperation of numerous individuals in government and industry. Jacki Clark of USBLM provided the federal leasing data. Jack Feuer of USBLM and Bob Fujimoto of USFS provided much useful information on regulatory issues. Dennis Olmstead and Dan Wermiel of DOGAMI furnished the data on drilling permits. Alex Sifford of ODOE and Susan Hartford of OWRD provided information on their agencies' activities for the year. Paul Lienau of OIT provided much of the information on direct-use projects around the state. David Sherrod, Terry Keith, and Steve Ingebritsen of USGS supplied accounts of USGS activities in Oregon. Don Hull of DOGAMI, Alex Sifford, and David Sherrod reviewed the paper. Jack Dymond of OSU reviewed the section on his study of Crater Lake.

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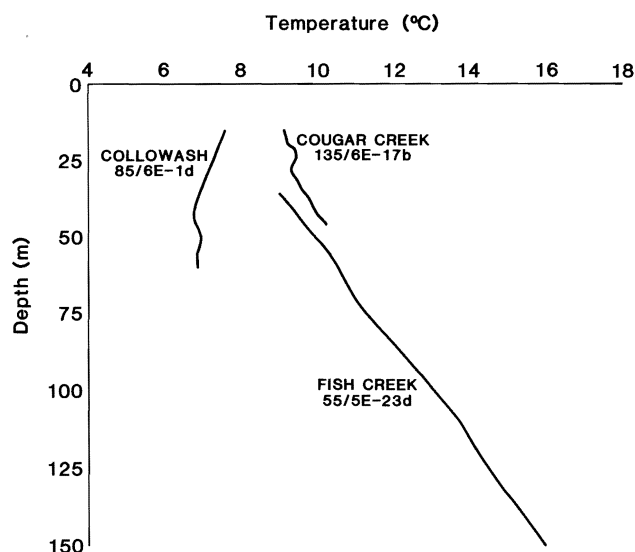


Figure 7. Temperature-depth curves for 1988 USGS drilling program.

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(Continued on page 117, *Geothermal*)

# Evaluating earthquake hazards in the Portland, Oregon, metropolitan area: Mapping potentially hazardous soils

by Ian P. Madin, *Seismic Hazard Geologist, Oregon Department of Geology and Mineral Industries*

## ABSTRACT

The scientific perception of earthquake hazards in Oregon is rapidly evolving, with the advent of new research that suggests that Oregon may be susceptible to earthquakes much more damaging than any in the state's short recorded history. Unfortunately, this new research does not provide the kind of well-constrained estimates of earthquake magnitude and epicentral location that are possible in areas such as Los Angeles or Salt Lake City.

Faced with the lack of good data about potential earthquake sources, the Oregon Department of Geology and Mineral Industries (DOGAMI) is attempting to approach the problem of earthquake design parameters by mapping surficial geology that may enhance earthquake-related hazards. The program centers on the production of 1:24,000-scale geologic maps that depict the distribution and thickness of Quaternary sediments that may cause amplification of ground shaking or lead to liquefaction during earthquakes. The mapping incorporates both surface geologic data and subsurface data collected from over 10,000 water-well, highway, and foundation-boring logs. DOGAMI anticipates that other workers will use these detailed geologic data to produce a variety of products of use to the engineering and planning communities. Among the planned and proposed uses are the following: (1) A regional map of spectral amplification zones in three period bands, based on surficial-unit thickness, measured and extrapolated shear-wave velocity profiles, and measured low-strain amplification factors; (2) a catalog of synthetic response spectra for a variety of sites and earthquake sources; and (3) liquefaction potential maps.

## INTRODUCTION

Recent seismological and geological research suggests that the Portland metropolitan area may be faced with significant earthquake hazards from several different sources and that the area may be susceptible to earthquakes far larger than any in local history. The level of concern is such that the Portland metropolitan area, along with the Puget Sound region, is now the first priority for research funded by the National Earthquake Hazard Reduction Program (NEHRP).

Traditionally, the magnitude, frequency, and location of potential earthquakes is evaluated by studying the rate and distribution of instrumental or historic seismicity and by analysis of the prehistoric activity of the surface traces of active faults. Neither of these approaches serves Oregon well, because the state has a short historic record, a poor instrumental net, and thick soil and vegetative cover in most of the densely populated areas. These problems and the nature of the regional tectonic setting mean that earthquake hazard is currently best understood in terms of geologic source zones that are capable of producing earthquakes.

A geologic understanding of earthquake source zones does not help the professional who is trying to update a Uniform Building Code (UBC)-type seismic zone map or who is selecting a design earthquake for a specific structure in Portland. Unfortunately, there is little hope that the data needed for more specific evaluations of potential earthquake characteristics will be available in the next few years. The Oregon Department of Geology and Mineral Industries (DOGAMI) has therefore chosen to study something for which there are abundant data: potentially responsive or liquefiable soils. Although we may not be able to predict how large an earthquake we may be faced with, through careful mapping of soils we can predict which sites could expect significant ground motion amplification or liquefaction in any given earthquake. To this end, DOGAMI

initiated a program of detailed mapping of the thickness and distribution of fine-grained unconsolidated sediments in the Portland metropolitan area, which will be largely completed in mid-1990. The detailed data provided by this program will be made available to the public and to other researchers for site-specific and regional studies of soils-dependent earthquake hazards.

## EARTHQUAKE SOURCE ZONES

Earthquake hazards in the Pacific Northwest stem from tectonic activity associated with the subduction of the Juan de Fuca oceanic plate beneath the North American continental plate in Oregon and Washington (Figure 1). The Juan de Fuca Plate converges on, and thrusts beneath, the North American Plate along the Cascadia Subduction Zone. Active seismicity along the southwestern and western margins of the Juan de Fuca Plate indicate that the subduction process is active, with a long-term convergence rate of several centimeters per year in a generally north-northeast direction. Convergence along the Cascadia Subduction Zone implies, for the Portland area, three types of earthquakes, each originating in a different zone (Figure

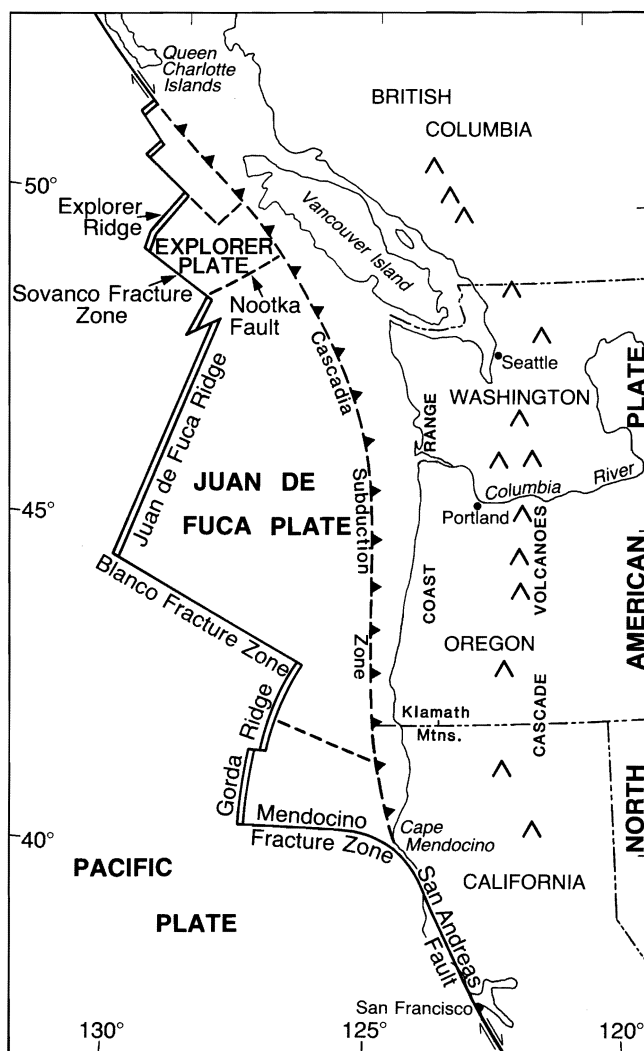


Figure 1. Plate-tectonic map of the Pacific Northwest.



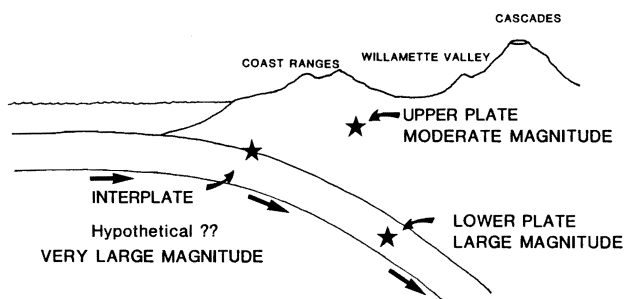


Figure 2. Schematic cross section through the Portland metropolitan area, showing the location of potential earthquake source zones.

2). These types of earthquakes are (1) shallow crustal earthquakes generated by faults in the immediate vicinity of Portland, (2) deep earthquakes originating in the subducted Juan de Fuca Plate beneath Portland, and (3) large earthquakes that may occur during periodic

slip along the interface between the Juan De Fuca and North American Plates.

All of the historical earthquakes in Portland are considered to be crustal events. To date, no causative faults have been identified, but recent geologic mapping (Beeson and others, 1989) has demonstrated that the Portland Hills are part of a complex fault zone and that other faults are common within the area. This suggests the possibility of a repeat of the magnitude (M)-5.1 Portland earthquake of 1962 almost anywhere in the region. The current state of fault mapping and the short record of historical earthquakes probably precludes an accurate estimate of the maximum possible crustal earthquake in the area.

Large earthquakes in the Puget Sound region originate at depths of 40-60 km within the subducted Juan de Fuca Plate. A small number of well-located deep earthquakes (Figure 3) indicates that the potentially seismogenic portion of the Juan de Fuca Plate exists beneath northwestern and southwestern Oregon (Weaver and Baker, 1988; Weaver and Shedlock, 1989). This suggests that the Portland area is underlain by an earthquake source zone capable of generating events similar in size to the 1949 Olympia earthquake (M 7.1),

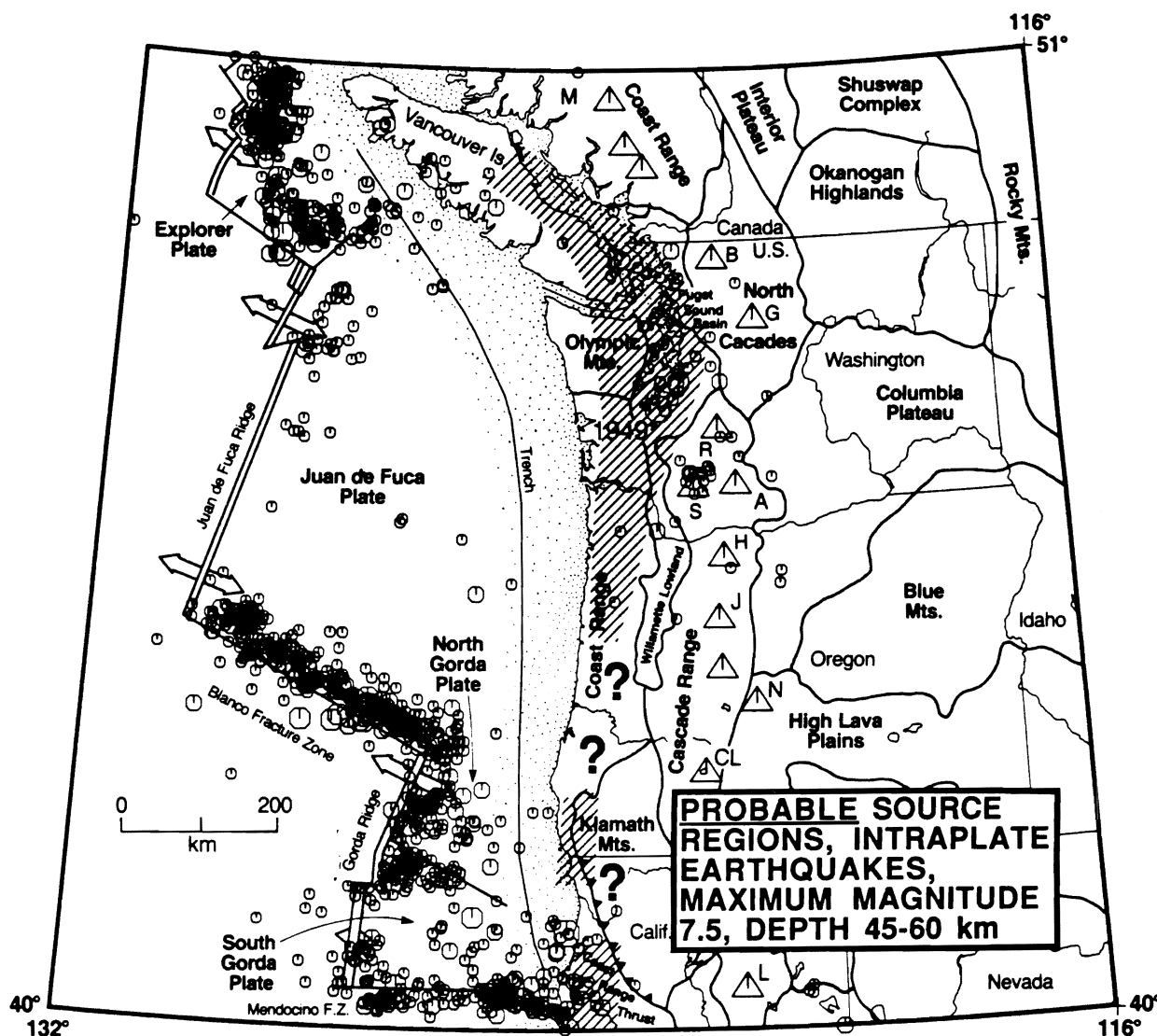


Figure 3. Schematic of probable source zones (hachured area) for deep earthquakes within the subducted Juan de Fuca Plate. Question marks indicate areas where there are no earthquakes located in the Juan de Fuca Plate. After Weaver and Shedlock, 1989.

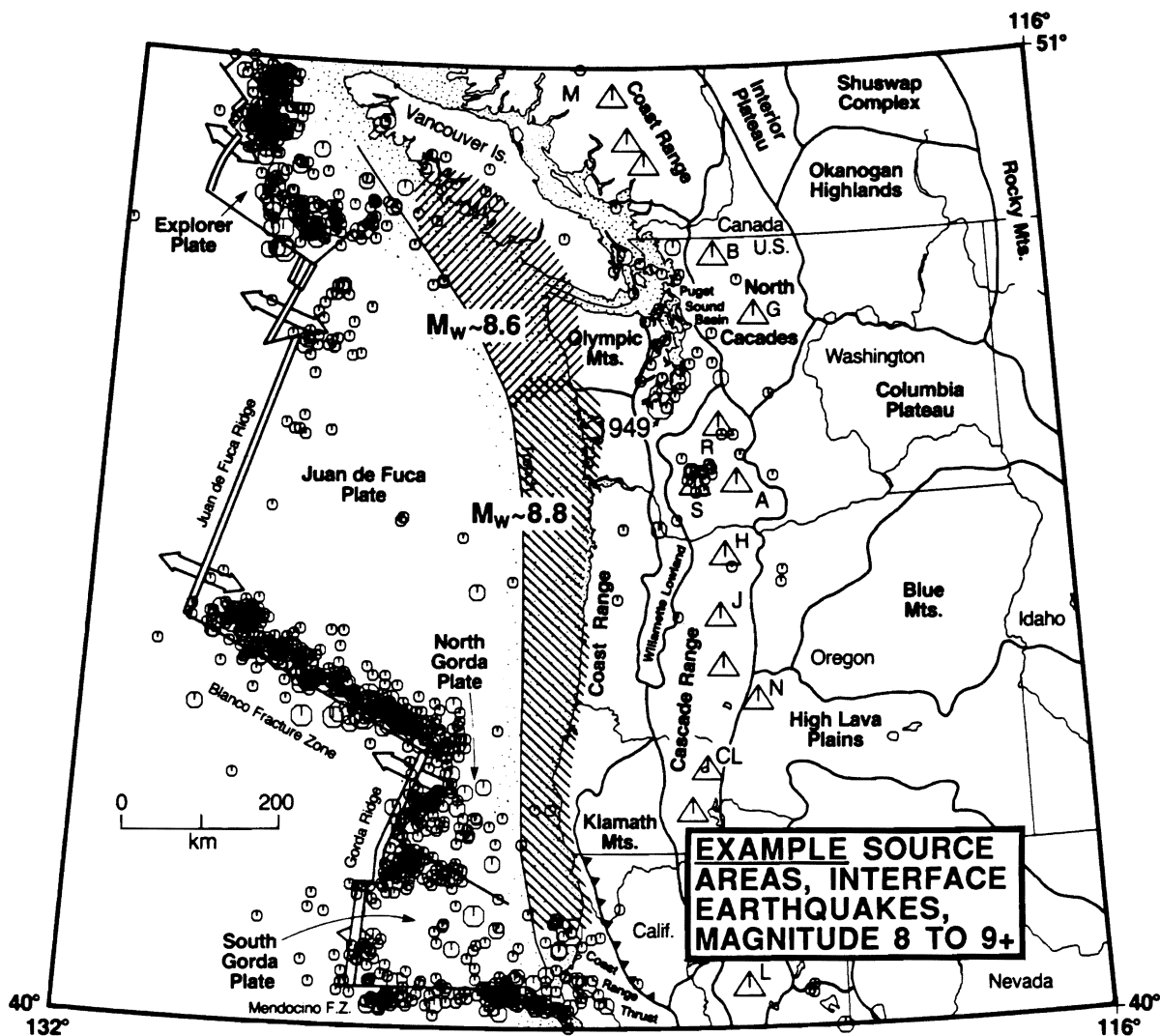
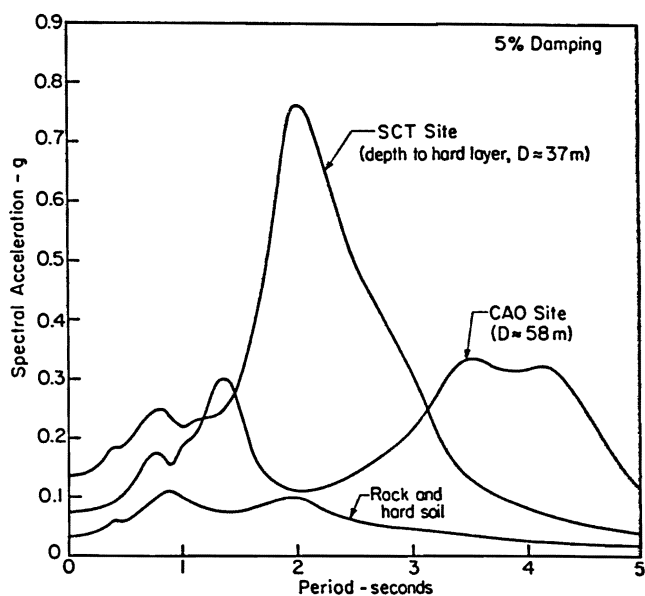


Figure 4. Schematic diagram showing examples of source zones and associated estimated magnitudes for hypothetical subduction interface earthquakes. Other combinations are possible. After Weaver and Shedlock, 1989.



although the overall rate of deep seismicity is orders of magnitude lower in Oregon than in Washington.

Finally, the suggestions of Heaton and Hartzell (1986) and observations of Atwater (1987) have triggered an intense scientific debate over the possibility that the Cascadia subduction zone may experience very large earthquakes due to periodic slip along the Juan de Fuca-North American Plate interface. Seismological data indicate that this interface is currently aseismic, which may mean that slip on the interface is always aseismic or that the interface is temporarily locked and accumulating strain between slip events. Geologic data provide strong evidence for repeated events of abrupt land-level changes and tsunamis that are very similar to those observed during the great earthquakes in Chile in 1960 and in Alaska in 1964. Conservatively, the entire coastal zone from northern California to British Columbia could be considered a potential source zone for large earthquakes (Figure 4).

Figure 5. Average acceleration response spectra for motions recorded on rock and hard-soil sites vs. soft-soil sites during the September 19, 1985, earthquake in Mexico City. SCT and CAO sites are soft-soil sites. After Seed and others, 1988.

MT. TABOR

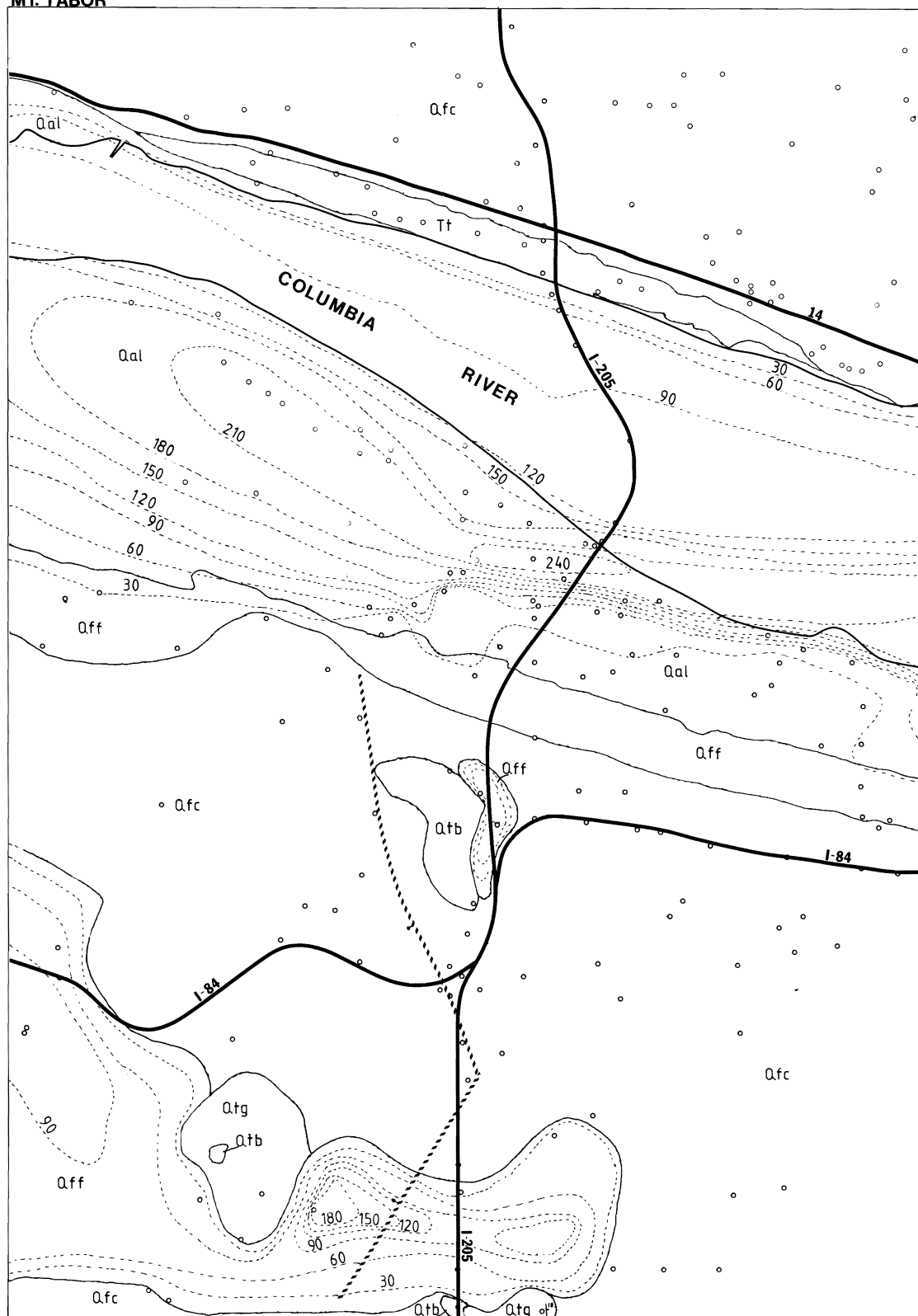


Figure 6. Preliminary geologic map of the Mount Tabor Quadrangle, Portland, Oregon. Small open circles are drill-hole data points. Qal = Recent alluvial sand and silt; Qff = outburst-flood silt of late Pleistocene age; Qfc = outburst-flood gravel of late Pleistocene age; Qtg = Pliocene-Pleistocene gravels; Qtb = Pliocene-Pleistocene basaltic lava flows; Tt = Pliocene gravels. Dashed lines are 30-ft isopachs on units Qal and Qff combined. Diagonal dashed lines are inferred buried faults. Heavy black lines are highways.

The three potential earthquake source zones outlined for Portland are similar in two important respects: (1) All indicate a significant possibility of maximum possible ground motions larger than any in the historical record, and (2) it is currently not possible to accurately predict probable maximum ground motions or earthquake return times from any of these sources.

This implies that for many years to come, engineers may be faced with increased concern about potential seismic hazards in Portland without any new quantitative ground-motion data on which to base designs. What is possible, however, is to generate quantitative data on soils and site-dependent shaking amplification and liquefaction potential for a postulated design earthquake.

## GROUND-MOTION AND LIQUEFACTION-POTENTIAL MAPPING

In any given earthquake, different sites at similar epicentral distances will experience ground shaking of different amplitude and spectral content due to the amplifying or attenuating effects of the surficial soil profile. Such amplification was, of course, dramatically demonstrated during the Mexico City earthquake of 1985 (Figure 5). Of particular concern are soft or cohesionless soils, which are widespread in the Portland area.

Ideally, one could map amplification due to soils empirically by comparing strong-motion records from a variety of sites. Unfortunately, earthquakes are not common in Portland, and there is only one strong-motion instrument in the area. This requires an approach to ground-response mapping based on an understanding of the density and shear-wave velocity profile at a great number of sites. Although these data can be obtained easily by measurements in a borehole, it is prohibitively expensive to collect data directly for the entire region. This means that we must couple a few direct measurements with an understanding of the local surficial geology in order to extrapolate data for a regional map. For this reason, the U.S. Geological Survey (USGS) and DOGAMI began a joint effort in 1987 to produce geologic maps on which to base evaluations of amplification potential.

DOGAMI's mapping program, which will be largely complete in mid-1990, will depict the thickness and distribution of young, fine-grained sediments and soils and the depth to bed rock throughout the developed portions of the Portland metropolitan area at a scale of 1:24,000. The mapping is based on field examination of surface exposures and topography and on the examination and interpretation of more than 10,000 foundation, highway, and water-well borehole logs. Figure 6, a map of the Mount Tabor Quadrangle, is an example of such a map.

Currently three uses have been proposed for the geologic data that DOGAMI has produced. A team of USGS scientists led by John Tinsley is planning to produce a series of ground-response maps for the area, using a technique that has been developed and refined in the Los Angeles, San Francisco, Salt Lake City, Seattle, and Olympia areas. Ivan Wong of Woodward Clyde Associates is proposing to produce a catalog of synthetic response spectra for a variety of characteristic sites. Finally, DOGAMI staff members are proposing to produce a series of liquefaction-potential maps for the area. It is crucial to note that none of these programs currently has firm funding.

## GROUND-RESPONSE MAPS

The USGS team uses an approach in which a series of data layers is used to map spectral amplification factors for three period bands. Recordings of relative ground motion are made at a variety of sites using quarry blasts, nuclear tests, or natural earthquakes. Boreholes are then drilled at the recording sites to measure the thickness, density, and shear-wave velocity of the unconsolidated sediments. The relations between the recorded spectral amplifications and the measured soil profile data are calculated and then extrapolated to the entire region, using data layers for the thickness of unconsolidated

sediment, depth to basement, and sediment density. The resultant maps depict zones of similar spectral amplification in the 0.5- to 1.0-, 1.0- to 3.0-, and 3.0- to 10.0-second period bands.

Many workers have questioned the validity of this technique, particularly the linear extrapolation of low-strain spectral-amplification measurements to the high strains expected in earthquakes. However, preliminary results from Olympia (Ken King, personal communication, 1989) indicate that spectral-amplification zones mapped through recordings of quarry blasts correspond closely to mapped intensity anomalies from historical Puget Sound earthquakes.

## SYNTHETIC RESPONSE SPECTRA

Workers at Woodward Clyde Consultants have developed a technique for generating synthetic response spectra for sites using the Band-Limited-White-Noise model with Random Vibration Theory (Darragh and others, 1989). Analysis of strong-motion records worldwide indicates that ground motions are controlled by the seismic moment of the earthquake and the rock properties (density, thickness, and shear-wave velocity) beneath the site. Comparisons of calculated spectra with strong-motion record derived spectra for historical Puget Sound earthquakes show excellent agreement (Figure 7). Ivan Wong of Woodward Clyde has proposed to generate a catalog of synthetic-response spectra for a variety of sites in the Portland area. The spectra would be based on site geology and shear-wave velocity data provided by DOGAMI and would model representative earthquakes from each of the potential source zones.

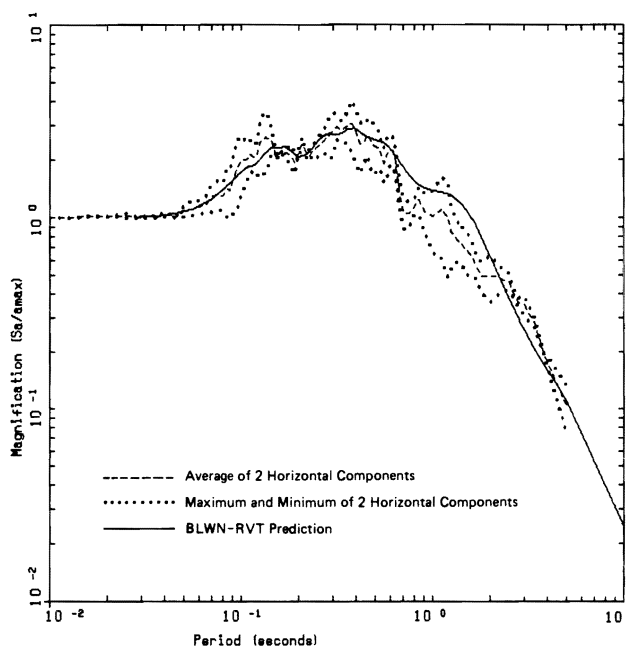


Figure 7. Observed and predicted acceleration response spectra of the earthquake at Olympia, Washington, on April 13, 1949, as recorded at the Highway Test Laboratory site in Olympia. After Darragh and others, 1989.

## LIQUEFACTION-POTENTIAL MAPPING

Fine-grained, cohesionless saturated soils are common in the Portland metropolitan area, particularly along the Willamette and Columbia River flood plains and in much of Washington County. Analysis and mapping of the liquefaction potential of these sediments have been proposed by DOGAMI staff in conjunction with Les Youd of Brigham Young University and will make use of the existing borehole and geologic database. Preliminary liquefaction-potential mapping of part of the Portland area is being carried out by the

(Continued on page 118, *Earthquake*)



# The great Grant County fireball, October 23, 1987

by Richard N. Pugh, Science Teacher, Cleveland High School, Portland, Oregon; Daniel J. Kraus, Former Chief Research Assistant/Deputy Director, Pine Mountain Observatory, University of Oregon; and Blain A. Schmeer, Professional Land Surveyor

The largest fireball ever reported in Oregon during this century occurred October 23, 1987, at 2:36 p.m., Pacific Daylight Time. This daylight fireball was seen from Wenatchee, Chelan County, Washington, on the north, to Burns, Harney County, Oregon, on the south. In Oregon, it was seen from Banks, Washington County, on the west, to Nyssa, Malheur County, on the east. This area covers 180,000 km<sup>2</sup>.

The following report is the result of over 250 interviews of eyewitnesses in Oregon of the event and over 1,000 hours in the field.

The fireball entered the atmosphere above the Cascade Mountains north of Mount Adams in Washington State. It moved southeast to Grant County, Oregon, where it exploded. The angle of descent was from 30° in Washington State to 90° at the end point. When it crossed the Columbia River near Celilo, Oregon, the angle of descent was about 35°.

The fireball was very bright. Those people who were in front of it reported that it was too bright to look at. Many reported it to be brighter than the sun and several times the diameter of the sun in the Dayville-Mount Vernon area of Grant County, Oregon.

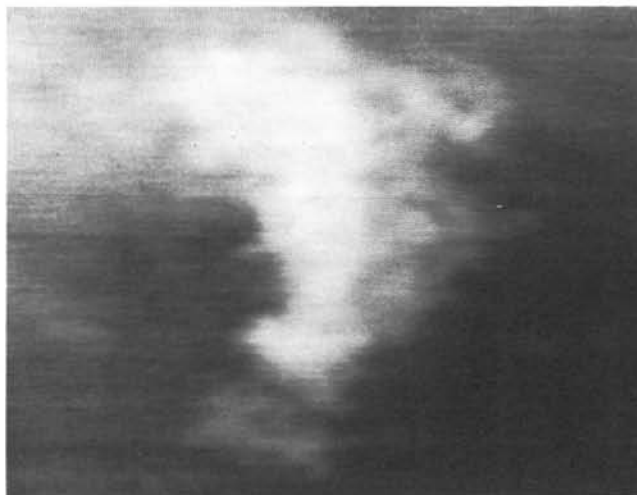
Most observers reported a round to teardrop-shaped fireball. All colors were reported, with orange and red being the most common. Most observers saw a long, white tail. Flames, sparks, and "smoke" were seen with the tail. The end point of the fireball's traverse occurred at an altitude of 29 km over sec. 24, T. 11 S., R. 27 E., W.M., at Grizzly Flats in the Blue Mountains of Grant County. Fragmentation near the end point was reported by some observers.

The fireball finally exploded, producing a large, columnar dust cloud. The dust cloud appears to have penetrated a thin overcast that was at an elevation of about 6,000 m. Most observers saw a blue-white cloud; many reported a black or brown center in the cloud. One person who was positioned almost directly under the cloud saw dark shapes falling out of the cloud. However, no one heard anything hit the ground. The cloud persisted for over 30 minutes.

Rumblings and sonic booms associated with the fireball were heard over an area extending north to the mouth of the Deschutes River in Sherman County, south to Seneca in Grant County, west to Mitchell in Wheeler County, and east to Prairie City in Grant County. Those in front of the fireball heard up to three heavy sonic booms that "caused the ground to move," rattled dishes, and flexed buildings. Those heavy booms were followed by up to 35 pops or cracks like a string of large firecrackers or a machine gun. Those under the fireball's path heard "wamp-wamp" sounds like a helicopter's blade. Swishing sounds were also reported. One to three heavy booms and five to 35 pops or cracks and rumblings lasting up to two minutes were reported by most people.

Within an hour of the event, the smell of sulfur was reported at Clarno in Wheeler County and the odor of hot metal at Canyon City in Grant County.

Anomalous sounds (sounds heard at the same time the fireball was seen) were reported from 6 km southwest of Cornelius in Washington County, over 300 km from the end point of the fireball. A hissing, whistling sound caused one person who was standing near TV and CB antennas on the roof of a house to look up and see the fireball. An observer traveling in an automobile near Boring in Clackamas County about 250 km from the end point heard a swishing sound and a faint boom at the same time he saw the fireball. A person located 8 km southeast of Oregon City in Clackamas County, approximately 260 km from the end point, heard a whooshing sound that caused him to look up and see the fireball. He was standing next to a patio with a metal roof.



VCR photos taken from 20 km southeast of Dale, Grant County, 48 km from the fireball's end point. The pictures were taken two seconds, three minutes, and five minutes after the sonic boom was heard. Photos courtesy of Pat Youmans.

At Kimberly in Grant County, a saddle horse started acting up for no reason, and then a strange sound caused the rider to look up and see the fireball descend. A "wamp-wamp" sound was heard as buildings quivered and the fireball exploded.

About 16 km east of Dayville, Grant County, 25 km from the fireball's end point, two sleeping dogs awoke, jumped up, and ran to the north window of a mobile home. Four or five seconds later, sonic booms hit the home. Loggers working at Pismire Camp, Grant County, 5 km from the end point heard a heavy sonic boom followed a short time later by a "wamp-wamp-wamp" sound of an object going end-over-end through the air. No impact was heard.

The behavior of the Grant County fireball is very similar to that of the fireball that produced the Pasamonte, New Mexico, meteorite, which fell March 24, 1933. The Pasamonte fireball produced a strewn field of meteorites that was 45 km long and 8 km wide (Nininger, 1936). Nearly a hundred small stony meteorites, none weighing over 300 grams, were recovered (Graham and others, 1985). Similarities between the two fireballs indicate that meteorites could be found anywhere along a line from Kimberly to Mount Vernon, Grant County.

Although the area over which the meteorite exploded is very rough terrain, the authors have been searching for pieces that fell to earth. The elevation is around 1,500 m, and the area is covered by a Ponderosa pine forest. Recovery of meteorite specimens is expected to be very difficult, and the authors urge anyone who may have found a piece to contact them.



*Photo of "smoke" cloud taken from 110 km west of fireball's end point one minute after the sonic boom. Photo by Dave Corliss.*

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- Graham, A.L., Bevan, A.W.R., and Hutchison, R., 1985, Catalog of meteorites, 4th ed.: Tucson, Ariz., University of Arizona Press.  
Nininger, H.H., 1936, The Pasamonte, New Mexico, meteorite: *Popular Astronomy*, v. 44, no. 6, p. 331-338. □

## Oregon boasts first gas storage site at Mist field

Energy demands on Northwest Natural Gas Company next winter will be met, at least in part, with natural gas from the company's new Columbia County storage field at Mist, the first gas storage site in Oregon.

When it is filled, the storage field will hold 7.5 Bcf of gas, sufficient peaking supplies for "the coldest 60-100 days of winter." The storage field is comprised of the Flora and Bruer pools, the largest pools discovered in the 10-year-old Mist Gas Field. Northwest Natural Gas began pumping gas back into the depleted pools in 1987, after they were taken out of production in 1984.

The distribution system of Northwest Natural Gas will be connected to the storage field by a new \$59,200,000 pipeline, which is expected to be ready for use in October. The 49-mi job began May 8 and is the largest capital construction project in the 130-year history of the Portland, Oregon, utility.

Because of the ancient Indian history of the Northwest, management of Northwest Natural Gas gave careful attention to the possibility that any right-of-way chosen for a new pipeline could disturb, or possibly destroy, Indian artifacts.

As it happened, the first route choice had to be abandoned because archeologists found "a heavy concentration of Indian artifact sites" and, because of that, a crew of experienced archeologists "walked every mile" of the route finally used, before trenching of the line was even begun.

This careful attention was rewarded when in the path of the pipeline were found 20 prehistoric Indian sites and seven historic sites, where discoveries have included small Stone Age tools such as mortars, pestles, chopping implements, and small flakes. Such finds indicate, according to the experts, that these sites had been used periodically over the last 6,000-8,000 years.

While the Mist storage field is a first for Oregon, natural-gas storage began in Canada in 1915. The Zoar field near Buffalo, New York, where storage was begun in 1916, remains the oldest continuously used gas storage field in the United States.



*Construction of Northwest Natural Gas Company feeder pipeline just east of Mist.*

Commenting in the company's annual report for 1988, Robert L. Ridgley, president, said that the storage facility "will allow the company to capitalize on the opportunities provided by open-access pipeline transportation," including summertime purchase of low-cost gas and realization of "substantial savings from reduced payments for peaking gas supplies."

Construction of the 16-in. line is expected to be completed by this fall.

—Reprinted with permission from *Oil and Gas Journal*, v. 87, no. 25 (June 19, 1989), p. 59.

## BOOK REVIEW

by Allen F. Agnew, Courtesy Professor of Geology, Oregon State University, Corvallis, Oregon 97331

**The Odyssey of Thomas Condon: Irish Immigrant, Frontier Missionary, Oregon Geologist**, by Robert D. Clark. Oregon Historical Society Press, 1989, 569 p., illust., \$29.95.

### **Condon, the teacher, minister, searcher for geologic answers**

Thomas Condon (1822-1907) was a teacher, a master teacher who broke with tradition in the middle and later 1800's by introducing his students to what was later to be called the "laboratory" method: learning by observation and analysis, rather than by memorization and regurgitation.

Condon was also a minister of the Congregational Church who had received his theological upbringing in a Presbyterian Seminary in Auburn, New York, in the 1840's. His belief in God as creator of the world and of all its natural wonders did not get in the way of his scientific observation and objectivity. Rather, by constantly adapting the biblical story of creation as he was assimilating new evidence and new knowledge, he wedded the two in his personal philosophy and in his teaching, which was especially evident during his many lectures and conversations on evolution. He was part of several decades of debate on the "evolution controversy," his lectures being widely reported in the newspapers. His opponents were not only those speaking for the "established" theology of the various Protestant missionary churches but also some of his professional colleagues in biology at the University of Oregon.

Condon's inquisitiveness was whetted by the books available to him from his earliest days in the United States. When he arrived in New York from Ireland in 1833, he was an 11-year-old Cork County native with no more than the basic elements of an education. He was fortunate to become a house boy and office boy for a physician who possessed a library. This search for knowledge continued to be fed during his three years of working on a farm in the Finger Lakes area of upstate New York, because the farmer there also had a library.

Condon's powers of observation outdoors and his joy in collecting rocks and fossils were stimulated by the geologic wonders of that beautiful Finger Lakes region, where he attended the Cazenovia Academy for a year and then for three years more engaged in what was to be his ultimate profession—teaching.

In 1849, Condon decided to enter the ministry, enrolling at the Presbyterian Seminary in Auburn, New York. The Presbyterians and Congregationalists in the middle 1800's had joint operations in upstate New York and Ohio, he found. He also learned that the issue of slavery and attendant conservatism had split the Presbyterians in 1837, as it had the Methodists and Baptists. Condon himself was an abolitionist.

While at seminary for three years, Condon taught 200 inmates at the nearby prison, who, as author Clark describes, "were overjoyed with the program—the only minutes in the week . . . when they were permitted human discourse" (p. 69). Condon empathized with them and was glad as a teacher to provide them with such a humanitarian release.

Upon graduation in 1852, Condon was appointed a missionary to the West by the American Home Mission Society. He learned that not only did the Society (of Presbyterians and Congregationalists) stipulate that the new missionaries be ordained but also expected them to be married. Condon was fortunate to have met Cornelia Holt that summer. She was a school teacher in a town near Buffalo, and they were married on October 31. With seven other missionaries and their families, they sailed from New York City on November 12 on a clipper ship for San Francisco. After 102 days and 17,000



Thomas Condon. Frontispiece in *The Odyssey of Thomas Condon*. Photo from archives of Oregon Historical Society, negative no. ORHI 55652.

miles on the ocean, the Condons and fellow missionary Obed Dickinson and his wife took another ship and, after five more days at sea, arrived in the small settlement of Portland on March 3, 1853.

For the next 54 years, Condon was to serve churches (as a missionary and minister), teach school (at both pre-college and college levels), and collect fossils and observe the geology around him. Condon's inquisitive nature, his powers of observation and analysis, and his strong religious foundation together enabled him to make his mark on the people of Oregon in the latter half of the 19th century. He was to be a lucid exponent of Darwin's modified evolutionary theory, which was to put him at odds with many of his religious counterparts in Oregon.

However, his continued discovery of fossils and his attempts to fit them into the evolutionary scheme of life brought him to the attention of the famous vertebrate paleontologists of the eastern United States. His collections and his thoughtful analysis of how they came to be there fueled the ambitions and abilities of two great movers and shakers during that period, Othniel C. Marsh of Yale University and Edward D. Cope of the Philadelphia Museum of Natural History. Joseph Leidy of the Smithsonian Institution likewise enabled that great museum to thrive on Condon's discoveries. By contributing to Condon's library in return for his fossil collecting, they helped Condon to grow intellectually and make his outstanding impact on Oregon.

Condon was not caught up in what we today call "publish or perish". Rather, partly because of his lack of formal training in geology and paleontology, but also because of his personal characteristic of searching for evidence and then seeking introspectively for the ultimate causes, he published only half a dozen articles on his researches. And those publications, he did not hesitate to state, were not intended as scientific discourses but were written for the general public.

Thus he carried out his lifelong bent of sharing his knowledge with those less tutored in those subjects than he—the great number



of people in pioneer Oregon who were seeking to establish themselves in this frontier land and at the same time attempting to understand the world in which they were living. Condon's two larger published works—his Report as State Geologist in 1867, and his magnum opus, "Two Islands—and What Came of Them" in 1902, were both directed toward the general public. It was part of his duty, and his joy, to pass along his knowledge, while at the same time he extended his own comprehension by responding to the questions addressed to him by his audiences and through the mail.

Condon's wife Cornelia may have lived to see him complete his book in 1901, but she was unable to share his triumph in its publication a year later. She was ill during much of the summer of 1901 at the cottage on Yaquina Bay and contracted typhoid fever in August. She died on September 2, 1901, at almost 70 years of age. Condon mourned, "The light of my life has gone out."

Condon flowered in The Dalles, where he had gone in March 1862 as a missionary. It was a lively settlement, with trade not only up and down the Columbia River but also into the gold-mining country to the southeast in the Shoshone (Blue) Mountains. This was the first of his missionary posts that could be called financially successful and thus made the "bringing of the word" and the saving of lives even more satisfying to such a very human person.

But more than that, The Dalles opened up the fantastic fossil-bearing strata of the John Day country to Condon's gaze and collecting acumen. He accompanied U.S. Cavalry there on some assignments to protect the white settlers from the "marauding" Indians who objected to the invasion of their lands in the 1860's.

Oregonians can mark Condon's 11 years in The Dalles as providing the nurturing environment for his greatest contributions—to geology, to his students, and to the general public.

Condon's huge capability at communicating his new knowledge, with newspaper accounts reporting his several series of lectures in The Dalles and in Portland, brought him to the attention of university administrators. Thus, in August 1873, he was attracted, with his collections, to Pacific University in Forest Grove as lecturer. Two years later, the budding University of Oregon offered Condon a professorship in Eugene, and his acceptance inaugurated the final and most significant segment of Thomas Condon's 85 years on earth.

In his first summer after going to the University of Oregon, Condon took his family on a trip of many days to the beach at Newport. Finding an unoccupied cabin on Nye Beach, they settled in and for the next thirty years were regular summer residents of the Newport area. Condon collected fossils, conducted "geological picnics," and recharged his batteries—just as U of O faculty do today, both in the Newport area and along other parts of the Oregon coast.

Condon was good for the University of Oregon, and the university was good to him. Clark's history of Condon's tenure at the U of O is as much a history of that institution as it is a history of the man. Condon was able to collect and study and contemplate the geology of new parts of the state—the coast, the Siskiyou (Klamath) Mountains in southwestern Oregon, and the Fossil Lake collecting grounds of east-central Oregon (east of the Cascade Mountains but south of the John Day country).

All the while, Condon was sharing his knowledge with his students, his fellow faculty members, and the townspeople—the latter two groups not always agreeing with him. The students, however, flourished under his "laboratory" method of instruction with which he replaced the traditional dull reading of textbooks or lecture notes, followed by recitation. His faculty colleagues did not take kindly to his nontraditional pedagogy, and they and some of the townspeople did not agree with him on his evolutionary theory or his accommodation of science and religion.

Nevertheless, they appreciated Condon so much that they named the campus oak trees for him, and they celebrated his birthdays—the 75th, the 80th, and annually thereafter. In June 1903, Condon requested that his teaching load be lightened and his salary reduced

to \$1,000, with the rest of the money going to an assistant. In 1905 he resigned, "due to the disabilities of old age," and the Regents regretfully elected him Professor Emeritus—at age 83. In January 1907, Condon became ill with influenza and could not get rid of a troublesome cough. Daughter Nellie C. McCornack brought him to her farmhouse about two miles west of Eugene to look after him. He lived for about three weeks and died on February 11, within three weeks of his 85th birthday.

In his old age, Condon had become a legend. Henry F. Osborn is said to have remarked candidly: "Professor Condon deserves the entire credit of the discovery of the upper Oligocene horses in the John Day."

### Clark, the chronicler, the historian

Robert D. Clark, President Emeritus of the University of Oregon, taught speech, rhetoric, and public address for many years there. He wrote an article on Thomas Condon, "From Genesis to Darwin: The Metamorphosis of Thomas Condon," which was published by the Oregon Historical Society in *The Western Shore* in 1975. Clark was also an author, along with Dorothy Velasco, of "An Evening with Thomas Condon," one of two pieces of history theater that toured eastern Oregon in 1981 and western Oregon in 1981-82 as part of Chautauqua 1981, a project of the Oregon Committee for the Humanities.

In the book being reviewed here, *The Odyssey of Thomas Condon*, author Clark enables us to live Condon's life along with him, sitting, as it were, in an adjoining chair as he talks or thinks. To some readers, used to speed-reading to the end of an account while hurrying over its details, such "extraneous" matter may constitute an impediment. To others, however, interested more in what made Condon "tick" and how he arrived at various decision points in his career and then made those decisions that constituted his life's history, this wealth of detail is most welcome—and makes Condon "come alive." Clark, a supreme chronicler, has done his job well.

For the geologist, Clark's book provides an interesting and exciting walk through the geological controversy surrounding the earth's origin and later development—uniformitarianism and catastrophism. And, for the geologist and the biologist, the Darwinian controversy and its effects on scientists and on the preservers of church doctrine ("as God wrote it") constitutes a thread that continues throughout the book. Condon's theological bent, coupled with his inquisitive mind and willingness to search for the truth and analyze it as a scientist does, enabled him to be an outstanding teacher—which he considered his main life calling.

Clark's book is very rewarding for a geologist such as this reviewer to read, because it enabled me to re-live my own professional life through the various stages that Condon himself had experienced a century earlier.

Clark's book is amazingly free from errors. Only three seem worth noting here:

(1) Along the Middle Fork of the Willamette River, Condon is said to have proceeded "southwest" from Eugene, whereas he really must have gone southeasterly (p.301).

(2) Sam Williston would have preferred that his name be spelled this way rather than "Willitson" (p. 512, footnote 19).

(3) Likewise, Henry Fairfield Osborn would have preferred this middle name rather than "Fairchild" (p. 435 and 563).

But, you won't wish to nitpick, anymore than I did as I was caught up in Clark's gripping account. Rather, you too will want to re-live Condon's Odyssey. I did—and I enjoyed it very much.

Yes, you should read Clark's *The Odyssey of Thomas Condon*. But you may also want to go to your library and check out the other biography of Thomas Condon, published by his daughter Nellie C. McCornack in 1928, *Thomas Condon: Pioneer Geologist of Oregon* (University of Oregon Press, 355 pages). Hers is full of correspondence between her father and the great names of vertebrate



paleontology in the latter half of the 19th century—Cope, Marsh, and Leidy.

Ellen T. Drake gave an interesting account (“Horse genealogy: The Oregon connection,” *Geology*, v. 6, no. 10, 1978, p. 587-591) of the Marsh/Cope feud, and of Marsh fending off other vertebrate paleontologists while grabbing for the line himself. She tells the story of Marsh (and his successors Charles Schuchert and Richard S. Lull), who claimed that Marsh himself had discovered the important Miocene horse link in the equine evolutionary tree—whereas the record shows that it was Condon who did so and who knew the significance of what he had found in 1871 when he sent his first collection to Marsh.

Shortly after Condon's death, the geological community recognized the value of his imprint upon vertebrate paleontology and geology in a memorial by Chester W. Washburne of the University of Chicago (“Thomas Condon,” *Journal of Geology*, v. 15, 1907, p. 280-282), who wrote:

... a life little known among scientists, yet a life of considerable service to geology.

Professor Condon was an unusual man in that he seemed to have no desire to publish the results of his study . . . But the writings of the scientists of his day . . . are full of references to Dr. Condon, and all of them acknowledge his contribution to science by exploration and theory.

Condon discovered the famous John Day beds . . . Here he found some of the specimens of three-toed horses on which Marsh based his theory of the evolution of that animal. In this instance, Marsh gave the discoverer scant credit for his work, and the type-specimens remained in Yale Museum until after Marsh died. The same thing happened to many other valuable specimens loaned to Marsh, Cope, Gabb, and others . . . it was unjust to Condon not to acknowledge more fully his services and not to return his specimens . . .

Condon was one of those rare men that study science from an inherent love of nature, not merely for self-advancement, or for the praise of men.

Clark's book is thoroughly footnoted and has a very complete index, making it easy for one who wishes to retrieve information to do so. Index maps of towns mentioned and a number of good photographs complement this very readable text. □

## MINERAL EXPLORATION ACTIVITY

### Rules for exploration permit to be drafted

The passage of House Bill 2088 requires persons conducting exploration in Oregon who disturb more than one acre or conduct drilling in excess of 50 ft to have an Exploration Permit from the Mined Land Reclamation Program (MLR) of the Oregon Department of Geology and Mineral Industries. MLR is currently drafting rules and will conduct public hearings on those rules in the fall of this year.

The intent of the Exploration Permit is to tailor environmental regulation to the proposed activity. Therefore, in brief, the Exploration Permit will have a lower fee than the operating permit and will

require a location map, a reclamation plan including drill-hole abandonment procedures, and a bond.

Until Exploration Permit rules are administratively approved, the term “Exploration” in the “Major metal-mining activity” table refers to the operating permit that is currently issued for exploration activities.

Readers who have questions or comments should contact Gary Lynch or Allen Throop at the MLR office in Albany, phone (503) 967-2039.

### Major metal-mining activity

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services, Inc.	T. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, Com
September 1988	QM Chevron Resources Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
January 1989	Silver Peak Formosa Exploration, Inc.	T. 31 S. R. 6 W. Douglas County	Copper, zinc	App, com
May 1989	Hope Butte Chevron Resources Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. □

## Recent DOGAMI publications

### REPORTS ON GORDA RIDGE STUDIES

(Released July 3, 1989)

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two reports presenting results of research on the Gorda Ridge, a sea-floor spreading region off the coast of southern Oregon and northern California. The reports, published as DOGAMI open-file reports, add more information to the ongoing research into the extent, nature, and effects of the hydrothermal venting that occurs along the mid-ocean ridge.

Both reports contain analyses of samples taken from the sea floor during dives of the submersible vessel *Sea Cliff* that were undertaken in 1988 and resulted in the discovery of the Sea Cliff Hydrothermal Field at the northern end of the Gorda Ridge. The findings confirm the existence of hydrothermal vents and hydrothermal activity in this field.

**Mineral Deposits Recovered from Northern Gorda Ridge: Mineralogy and Chemistry** (DOGAMI Open-File Report O-89-09, \$5) was prepared by Martin R. Fisk and Katherine J. Howard of the Oregon State University College of Oceanography. The 26-page report presents and discusses analyses of samples taken from site GR-14 and analyzed by X-ray diffraction and atomic absorption.

**Preliminary Analysis of Four SESCA Samples from the Gorda Ridge** (DOGAMI Open-File Report O-89-11, \$4) was prepared by John Wiltshire, Gary McMurtry, and Ned Murphy of the Hawaii Institute of Geophysics, University of Hawaii. The 6-page report presents and discusses analyses of samples from the SESCA site located in the Escanaba Trough.

### GEOLOGIC QUADRANGLE MAP FOR OWYHEE REGION

(Released July 12, 1989)

A new geologic map describes in detail the geology and mineral potential of a part of the Owyhee region in eastern Oregon. The identified potentially valuable mineral resources include geothermal energy, gold, and semiprecious gemstones.

**Geology and Mineral Resources Map of the Owyhee Dam Quadrangle, Malheur County, Oregon**, by DOGAMI geologist Mark L. Ferns, has been released in DOGAMI's Geological Map Series as map GMS-55. The price is \$4.

The publication, resulting from an ongoing study of southeastern Oregon areas with a potential for mineral resources, was prepared in cooperation with the U.S. Geological Survey (USGS) and partially funded by the COGEOMAP program of the USGS.

The Owyhee Dam 7½-minute quadrangle covers approximately 48 square miles along the Owyhee River, approximately from below Owyhee Dam in the southwest to the city of Owyhee in the northeast. The new two-color map of the quadrangle (scale 1:24,000) identifies 16 rock units, the oldest of which may date back 25 million years before the present. Geologic structure is described both on the map and in two accompanying cross sections. The approximately 28- by 40-inch map sheet also includes a discussion of the area's mineral-resource potential and tables showing whole-rock and trace-element analyses of rock samples.

A variety of valuable and potentially valuable mineral resources were found or indicated by the study, including hot-spring systems at Deer Butte Spring and Snively Hot Spring, indicators for gold in areas of hot-spring-type alteration, silica sand, and semiprecious gemstones in the form of agate and jasper. Except for casual collecting of various types of chalcedony, no mineral-resource production has occurred in the quadrangle.

### GEOLOGIC QUADRANGLE MAP FOR LAKE OSWEGO AREA

(Released August 16, 1989)

The Lake Oswego Quadrangle covers an area just south of the center of Portland, Oregon. A new geologic map of the quadrangle

is intended to serve as an important basic tool for earthquake hazard reduction in the Portland area.

**Geologic Map of the Lake Oswego Quadrangle, Clackamas, Multnomah, and Washington Counties, Oregon**, by Marvin H. Beeson and Terry L. Tolan of the Portland State University Geology Department and DOGAMI geologist Ian P. Madin, has been released in DOGAMI's Geological Map Series as map GMS-59. The price is \$6.

The map was produced and published as part of an earthquake hazard study in the Portland metropolitan area and funded by the U.S. Geological Survey (USGS) and the National Earthquake Hazard Reduction Program.

The new map depicts an area in which several basalt layers of the Columbia River Basalt Group can be identified and mapped individually. This allowed the researchers to map faults with an unprecedented degree of confidence and accuracy. The map is the most detailed and up-to-date geologic map of the Portland area that is currently available.

The full-color map (scale 1:24,000) is printed on a sheet approximately 28 by 40 inches in size. It identifies and describes 16 rock units ranging from 40-million-year-old basement rock to the deposits from late Ice Age catastrophic floods. The map sheet also includes three geologic cross sections and a table of compositional averages of samples from the basaltic units of the map area.

### EXPLORATION AND LITERATURE ON OIL AND GAS IN OREGON

(Released August 21, 1989)

After nearly 90 years of oil and gas exploration, Oregon today has over 350 wells and a producing natural-gas field. Exploration efforts and published studies during those years have been summarized and listed in two new publications from DOGAMI.

**Hydrocarbon Exploration and Occurrences in Oregon**, by DOGAMI Petroleum Engineer Dennis L. Olmstead, has been published as DOGAMI Oil and Gas Investigation 15 (OGI-15). The 78-page publication contains introductory discussions of the history of oil and gas exploration in Oregon, the sedimentary basins of the state, and the Mist Gas Field, Oregon's only producing field.

These texts are followed by two tables listing available information about all known oil and gas wells and hydrocarbon occurrences in the state and in federal waters offshore. Grouped by county, the individual wells list names of the wells and of their present and past operators, locations, and drilling dates and depths, and notes that may include information on the method of drilling, the geology, hydrocarbon shows, and references in the literature. Two additional tables present gas analyses from certain wells and water analyses made on samples from exploratory wells.

While OGI-15 lists, in its bibliography, only the references mentioned in the text and tables, a comprehensive bibliography by the same author is contained in DOGAMI Open-File Report O-89-10. This report, **Bibliography of Oil and Gas Exploration and Development in Oregon, 1896-1989**, is intended to serve as a supplement to OGI-15. Comprising 33 pages, its author list includes approximately 750 citations and is followed by a county index listing cross-references for citations associated with a particular county.

Oil and Gas Investigation 15 sells for \$7, Open-File Report O-89-10 for \$5.

All new publications are available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201-5528. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under \$50 require prepayment except for credit-card orders. □

## Additional sources of information on Thundereggs

The July issue of *Oregon Geology* (v. 51, no. 4, p. 87-89) contained a short article on Thundereggs in Oregon that has also been made available to the public as a colored brochure. A list of references containing additional information about Thundereggs for those readers who would like to learn more about them is printed below.

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—Paul F. Lawson

## OIL AND GAS NEWS

### Drilling begins at Mist Gas Field

Drilling began at the Mist Gas Field during July, when DY Oil spudded its well Neverstill 33-30. The well is located on the west side of the field in SE¼ sec. 30, T. 6 N., R. 5 W., Columbia County. Proposed total depth is 3,000 ft. DY Oil has permits for two additional locations at Mist Gas Field. Taylor Drilling Company, Chehalis, Wash., is the contractor.

### Mist production for 1989

Through June, 16 gas wells were producing at Mist Gas Field. Cumulative production from January through June was about 1.1 billion cubic feet (Bcf) of gas. In addition, eight gas wells were completed at the field and are shut in, awaiting pipeline connection.

A report containing complete production figures for Mist Gas Field, from its discovery in 1979 through 1988, is available at the Oregon Department of Geology and Mineral Industries (DOGAMI). For each well, the report contains data on monthly and cumulative production, tubing and casing pressures, Btu values, and revenue generated from gas sales. The report will be sold together with the Mist Gas Field Map (Open-File Report O-89-2), which shows the locations of all wells drilled and permitted, as well as dates and depths of drilled wells and names of their operators. Both the map and the production report will be updated annually and sell for \$7.

### Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
431	Northwest Fuel Hammerberg 32-14-65 36-009-00260	NE¼ sec. 14 T. 6 N., R. 5 W. Columbia County	Permitted; 2,700.
432	ARCO Columbia Co. 34-8-75 36-009-00261	SE¼ sec. 8 T. 7 N., R. 5 W. Columbia County	Permitted; 2,760.
433	ARCO Meridian 34-31-65 36-009-00262	SE¼ sec. 31 T. 6 N., R. 5 W. Columbia County	Application withdrawn. □

### (Geothermal, continued from page 105)

- Sherrod, D.R., 1988, Geologic and geothermal summary of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon, in Sherrod D.R., ed., 1988, Geology and geothermal resources of the Breitenbush-Austin Hot Springs area, Clackamas and Marion Counties, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-88-5, p. 63-67.
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## ABSTRACTS

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

**A SEISMIC-REFRACTION STUDY OF A PORTION OF THE NORTHEASTERN MARGIN OF THE TUALATIN VALLEY, OREGON**, by David J. Nazy (M.S., Portland State University, 1987), 81 p.

The Tualatin Valley is a well-defined elliptical basin centered at Hillsboro, with a major axis trending roughly N. 65° W. The valley is bordered on the northeast by the Tualatin Mountains (Portland Hills), which are a faulted, northwest-trending asymmetrical anticline. Topographic and geophysical evidence have defined the Portland Hills fault, which occurs along the northeast side of the Tualatin Mountains. The possibility that a fault or fault zone occurs along the southwest side of the Tualatin Mountains was investigated in this study.

Boring Lavas, occurring on the southwest side of the Tualatin Mountains and having been erupted through the Columbia River basalt, may define zones of fracture or faulting in the Columbia River basalt. An exposed "window" of sediment is located near the town of Bonny Slope on the southwest side of the Tualatin Mountains. This sedimentary unit is presumed to be marine in origin, stratigraphically below the Columbia River basalt. Exposure of this unit at this location may be the result of landsliding, faulting, or paleotopographic highs during the deposition of the Columbia River basalt.

Seismic-refraction methods were used to produce shallow (0-50-m) geologic models near the areas of the proposed fault zone. The refraction models indicate that Columbia River basalt roughly parallels the surface topography at an average depth of 15 m and is overlain by a weathered zone ranging in thickness from 5 to 15 m. The basalt is broken up into blocks, mainly in the southeastern half of the study area. Data collected through this study indicate that the sedimentary unit at Bonny Slope is not underlain by Columbia River basalt. This provides further evidence that this unit is part of the Scappoose Formation, although it is uncertain as to whether this feature is related to faulting or paleotopographic highs.

**A MAGNETOTELLURIC INVESTIGATION OF THE LOOKOUT MOUNTAIN AREA IN THE CENTRAL OREGON HIGH CASCADES**, by William W. Clingman (M.S., University of Oregon, 1988), 81 p.

A large gravity anomaly and numerous north-trending volcanic lineaments suggest that the area around Lookout Mountain in the central Oregon High Cascades should provide a significant test of the magnetotelluric sounding method in identifying and characterizing subsurface structures in young volcanic areas. Data from 34 wide-band magnetotelluric sites in the area were analyzed; the results are discussed in terms of the known and inferred surficial and subsurface geology of the area.

As in other areas of the Cascade Range, the electrical profile of the crust in the study area consists of shallow and deep conductive layers separated by a thick resistor. Resistivities in the surface layer show excellent correlation with surface geology. Low-frequency electrical strikes trend northeast, roughly parallel to the strike of the gravity anomaly and to other large-scale features of the region. North-trending volcanic lineaments do not appear to exert significant control over resistivity distribution in the area.

**THE GEOLOGY, GEOCHEMISTRY, AND ALTERATION OF RED BUTTE, OREGON; A PRECIOUS-METAL-BEARING PALEO HOT SPRING SYSTEM**, by C. Susan Evans (M.S., Portland State University, 1986), 133 p.

Red Butte is located 60 km south of Vale, Oregon, about 20 km west of the Oregon/Idaho border. The butte is within eastern Oregon's Owyhee Upland physiographic province, at the intersection of the Western Snake River Plain, the High Lava Plains, and the Northern Basin and Range provinces.

The butte is composed of Miocene to Pliocene lacustrine and fluvial volcanoclastic sediments. The topography of the butte is controlled by silicification of the sandstones and mudstones that cap it. Silicification and hydrothermal alteration are both structurally and stratigraphically controlled. North-trending normal faults dominate the area and show progressively less offset in younger units. Strong northwest and minor northeast faults also cut the area. □

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*(Earthquake, continued from page 110)*

Portland Water Bureau and Leon Wang of Old Dominion University as part of an NEHRP-funded analysis of the seismic resistance of the Portland water system.

### CONCLUSION

The understanding of earthquake hazards in Portland is rapidly improving and suggests that the threat is greater than previously considered. Although it will still be many years before it will be possible to produce accurate probabilistic acceleration maps for the area, it is currently possible to assess relative ground-motion or ground-failure effects for a given earthquake using the detailed surficial geologic maps being produced by DOGAMI. Several studies have been proposed to turn these data into products useful to the engineering and planning communities, and more are encouraged. It is easy to be complacent about earthquakes in Oregon, and there is no question that the risk in adjacent states is far greater. Still, the writing of this paper was interrupted by the Camas earthquake of August 1, 1989, a reminder that the Portland area is tectonically active. We must continue to make use of all available resources to ensure that our community is earthquake-safe.

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## AVAILABLE DEPARTMENT PUBLICATIONS

### GEOLOGICAL MAP SERIES

	Price	No. copies	Amount
GMS-5. Geologic map, Powers 15-minute quadrangle, Coos and Curry Counties. 1971	3.00		
GMS-6. Preliminary report on geology of part of Snake River canyon. 1974	6.50		
GMS-8. Complete Bouguer gravity anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-9. Total-field aeromagnetic anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-10. Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	3.00		
GMS-12. Geologic map of the Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	3.00		
GMS-13. Geologic map, Huntington and part of Olds Ferry 15-min. quadrangles, Baker and Malheur Counties. 1979	3.00		
GMS-14. Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00		
GMS-15. Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	3.00		
GMS-16. Free-air gravity anomaly map and complete Bouguer gravity anomaly map, south Cascades, Oregon. 1981	3.00		
GMS-17. Total-field aeromagnetic anomaly map, south Cascades, Oregon. 1981	3.00		
GMS-18. Geology of Rickreall, Salem West, Monmouth, and Sidney 7½-min. quads., Marion/Polk Counties. 1981	5.00		
GMS-19. Geology and gold deposits map, Bourne 7½-minute quadrangle, Baker County. 1982	5.00		
GMS-20. Map showing geology and geothermal resources, southern half, Burns 15-min. quad., Harney County. 1982	5.00		
GMS-21. Geology and geothermal resources map, Vale East 7½-minute quadrangle, Malheur County. 1982	5.00		
GMS-22. Geology and mineral resources map, Mount Ireland 7½-minute quadrangle, Baker/Grant Counties. 1982	5.00		
GMS-23. Geologic map, Sheridan 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-24. Geologic map, Grand Ronde 7½-minute quadrangle, Polk/Yamhill Counties. 1982	5.00		
GMS-25. Geology and gold deposits map, Granite 7½-minute quadrangle, Grant County. 1982	5.00		
GMS-26. Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00		
GMS-27. Geologic and neotectonic evaluation of north-central Oregon. The Dalles 1°x2° quadrangle. 1982	6.00		
GMS-28. Geology and gold deposits map, Greenhorn 7½-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-29. Geology and gold deposits map, NE¼ Bates 15-minute quadrangle, Baker/Grant Counties. 1983	5.00		
GMS-30. Geologic map, SE¼ Pearsoll Peak 15-minute quadrangle, Curry/Josephine Counties. 1984	6.00		
GMS-31. Geology and gold deposits map, NW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-32. Geologic map, Wilhoit 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-33. Geologic map, Scotts Mills 7½-minute quadrangle, Clackamas/Marion Counties. 1984	4.00		
GMS-34. Geologic map, Stayton NE 7½-minute quadrangle, Marion County. 1984	4.00		
GMS-35. Geology and gold deposits map, SW¼ Bates 15-minute quadrangle, Grant County. 1984	5.00		
GMS-36. Mineral resources map of Oregon. 1984	8.00		
GMS-37. Mineral resources map, offshore Oregon. 1985	6.00		
GMS-38. Geologic map, NW¼ Cave Junction 15-minute quadrangle, Josephine County. 1986	6.00		
GMS-39. Geologic bibliography and index maps, ocean floor and continental margin off Oregon. 1986	5.00		
GMS-40. Total-field aeromagnetic anomaly maps, Cascade Mountain Range, northern Oregon. 1985	4.00		
GMS-41. Geology and mineral resources map, Elkhorn Peak 7½-minute quadrangle, Baker County. 1987	6.00		
GMS-42. Geologic map, ocean floor off Oregon and adjacent continental margin. 1986	8.00		
GMS-43. Geologic map, Eagle Butte and Gateway 7½-min. quads., Jefferson/Wasco Co. 1987	\$4.00; as set with GMS-44 & -45.		10.00
GMS-44. Geologic map, Seekseequa Junction/Metolius Bench 7½-min. quads., Jefferson Co. 1987	\$4.00; as set with GMS-43 & -45.		10.00
GMS-45. Geologic map, Madras West and Madras East 7½-min. quads., Jefferson County. 1987	\$4.00; as set with GMS-43 & -44.		10.00
GMS-46. Geologic map, Breitenbush River area, Linn/Marion Counties. 1987	6.00		
GMS-47. Geologic map, Crescent Mountain area, Linn County. 1987	6.00		
GMS-48. Geologic map, McKenzie Bridge 15-minute quadrangle, Lane County. 1988	8.00		
GMS-49. Map of Oregon seismicity, 1841-1986. 1987	3.00		
GMS-50. Geologic map, Drake Crossing 7½-minute quadrangle, Marion County. 1986	4.00		
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VOLUME 51, NUMBER 6

NOVEMBER 1989



**PLEISTOCENE MAMMOTH TUSK FOUND NEAR MITCHELL**  
Also in this issue:  
Industrial minerals in Oregon  
Titanium and zirconium in Northwest beach sands

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## COVER PHOTO

Mammoth tusk found near Mitchell, Wheeler County. This top view shows tusk in place, prior to jacketing (coating it with a protective layer of plaster of paris). Article beginning on page 129 discusses the find and its display in the Prineville District Office of the U.S. Bureau of Land Management.

# OIL AND GAS NEWS

## Drilling activity at Mist

DY Oil drilled three wells at the Mist Gas Field during August. The Neverstill 33-30 was drilled to a depth of 2,225 ft and was completed as a gas producer. The Forest Cav 13-6 and Burris CC 24-8 were drilled to a depth of 1,796 and 2,684 ft, respectively, and both were plugged and abandoned.

ARCO commenced operations at Mist during August, drilling the CER 41-16-64 to a depth of 2,105 ft and suspending the well. Details have not been released. The CER 24-18-64 was drilled to a depth of 1,810 ft and was plugged and abandoned. ARCO plans to drill at least three more wells at Mist this year and will attempt recompletions and other work on wells at the field.

## Rulemaking to begin on HB-2089

House Bill 2089 was passed during the 1989 legislative session. The bill is to provide for ground-water protection and surface reclamation when shallow exploration holes are drilled by the oil and gas industry in Oregon. These holes may be drilled for seismic surveys or other purposes. Interested parties may contact Dan Wermiel at the Oregon Department of Geology and Mineral Industries for details.

## Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
434	ARCO Columbia Co. 13-3-55 36-009-00263	SW¼ sec. 3 T. 5 N., R. 5 W. Columbia County	Permitted; 1,655.
435	ARCO Columbia Co. 13-4-54 36-009-00264	SW¼ sec. 4 T. 5 N., R. 4 W. Columbia County	Permitted; 2,025.
436	ARCO Cav. En. Res. 13-1-55 36-009-00265	SW¼ sec. 1 T. 5 N., R. 5 W. Columbia County	Permitted; 1,645.
437	ARCO Oregon 34-25-66 36-007-00022	SE¼ sec. 25 T. 6 N., R. 6 W. Clatsop County	Permitted; 2,280. □

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# Industrial minerals in Oregon

by Ronald P. Geitgey, Oregon Department of Geology and Mineral Industries

## ABSTRACT

A wide variety of industrial minerals is produced in Oregon for regional, national, and international markets. The estimated total value of nonfuel mineral production in Oregon in 1988 was \$169 million, virtually all of which was from industrial minerals. Sand, gravel, and crushed rock accounted for approximately \$115 million.

Limestone is quarried from one location for cement production and sugar-beet processing and from two other locations for agricultural uses. Diatomite is produced by two companies, one for filter aids and the other for pet litter and oil absorbents. Bentonite clay from two operations is used primarily for civil-engineering applications, and structural clays are used by two brick manufacturers. Pumice from two areas is sold to concrete-block producers, and lesser amounts are used for landscaping and for stone-washing certain garments. The zeolite mineral clinoptilolite is processed for absorbents and odor-control products. Exploration and limited production of perlite continues, and emery is produced for nonskid surface coatings. Quartzofeldspathic beach dunes supply material for container glass production, and quartz is quarried for nickel smelting, filter beds, poultry grit, and decorative uses. Talc, in the form of soapstone, has an international market as fine-quality art-carving material, and gemstone production includes agates, opal, obsidian, and sunstone, a calcic plagioclase feldspar.

Many commodities produced in the past in Oregon merit reevaluation. Some of these are brick clays, chromite, expandable shales, foundry sands, gypsum, iron-oxide pigments, peat, and building stone, including gray granites, white marble, black marble, sandstones, and volcanic tuffs. Production ceased for most of these because of market conditions and increased costs rather than product quality or deposit reserves.

Several other commodities have the potential for new or increased production. Some have been evaluated; others are known occurrences that have geologic potential for commercial development. They include bentonite clay, borates, feldspar, ferruginous bauxite, fuller's earth, kaolin clay, nepheline syenite, perlite, and talc.

## INTRODUCTION

Industrial, or nonmetallic, minerals are often unnoticed commodities, but their production is essential to nearly all phases of a modern economy, including construction, manufacturing, and production of food, fuels, and fibers. Their total value far exceeds that of the metals in both national and world markets.

The term "industrial minerals" defies suc-

cinct, comprehensive definition. It encompasses natural rocks and minerals as well as manufactured products such as cement and lime. While often termed "nonmetals", some industrial minerals are, in fact, metal ores that are utilized for properties other than their contained metal. Bauxite, for example, is the ore of aluminum metal but also the basis for some refractories (heat-resistant materials), abrasives, chemicals, and pharmaceuticals. Similarly, gemstones such as diamond and sapphire are included in some discussions of industrial minerals, in part because of their role as abrasives in the form of industrial diamonds and corundum. Perhaps it is simpler to say that industrial minerals are naturally occurring rocks and minerals and certain products manufactured from them that are not used as metal ores or as fuels.

The uses of industrial minerals are highly diverse. Some are dependent on physical properties such as strength, hardness, softness, color, and density, while other uses, including chemicals, fertilizers, ceramics, and glass, are dependent on chemical composition. Hard or tough minerals such as quartz, garnet, or emery are used as abrasives and on wear-resistant surfaces. Soft minerals such as talc and graphite are valuable for their lubricity (slipperiness) and for the minimal wear they have on the equipment used to make products containing them. Strength, flexibility, and density are

among several characteristics of plastics that depend on industrial-mineral content. In construction, industrial minerals are used as aggregates (sand, gravel, crushed rock), building stone, cement, plaster, and roofing materials. In paints, industrial minerals determine color, covering capacity, gloss, toughness, washability, and sag resistance. The paper industry uses numerous minerals as fillers and coaters to control various properties of the paper, such as bulk, weight, smoothness, opacity, and ink retention. Numerous juices, beverages, oils, and other liquids are filtered through layers or beds of certain industrial minerals to remove impurities and to clarify the product.

Many industrial minerals can perform several different functions. For example, quartz in its several forms can be used in numerous applications, including glass, electronics, refractories, abrasives, aggregates, fillers, filters, and foundry sands. Limestone may be used for cement, aggregate, building stone, chemicals, glass, plastics, paper, agriculture applications, sugar refining, and treatment of waste liquids and gases.

As a result of this diversity of uses and properties, exploration for and evaluation of industrial minerals are often highly specialized fields. A chemical assay may be useful, but often physical properties, type of impurities, and distance from potential markets are far more important. In some applications, the precise

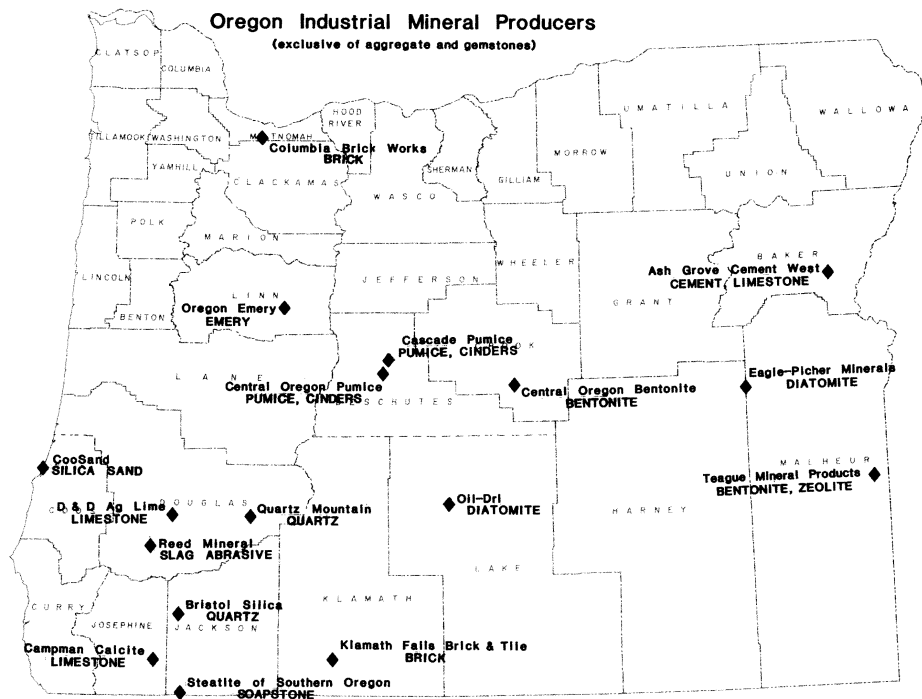


Figure 1. Current producers of industrial minerals in Oregon.

Table 1. *Production and occurrence of industrial minerals in Oregon. A=Documented occurrence. B=Past production. C=Present production.*

Mineral	A	B	C
Abrasives			
Alumina	X		
Emery	X		X
Gamet	X		
Silica	X	X	X
Slag	X		X
Aggregates			
Crushed stone	X	X	X
Sand and gravel	X	X	X
Alunite	X		
Asbestos, chrysotile	X	X	
Barite	X		
Bauxite, ferruginous	X		
Borates	X	X	
Building stone			
Basalt	X	X	
Granite	X	X	
Limestone	X	X	
Marble	X	X	
Sandstone	X	X	
Tuff	X	X	
Chlorite	X		X
Chromite	X	X	
Cinders	X	X	X
Clays			
Bentonite	X		X
Fuller's earth	X		
Kaolin	X		
Refractory	X	X	
Structural	X	X	X
Diatomite	X	X	X
Expandable shale	X	X	
Feldspar	X		
Fluorspar	X		
Foundry sand	X	X	
Gemstones			
Agate, jasper	X	X	X
Gamet	X	X	
Jade, nephrite	X	X	
Obsidian	X	X	X
Opal	X	X	X
Rhodonite	X	X	
Sunstone, feldspar	X	X	X
Graphite	X		
Gypsum/anhydrite	X	X	
Iron oxides	X	X	
Lithium minerals	X		
Limestone			
Agricultural	X	X	X
Cement	X	X	X
Sugar refining	X		X
Mica	X		
Nepheline syenite	X		
Olivine	X		
Optical calcite	X		
Peat	X	X	
Perlite	X	X	X
Pumice	X	X	X
Silica			
Cristobalite	X		
Quartzite	X	X	X
Sand	X	X	X
Sulfur	X		
Talc, soapstone	X	X	X
Vermiculite	X		
Wollastonite	X		
Zeolites			
Chabazite	X		
Clinoptilolite	X		X
Erionite	X		
Mordenite	X		
Phillipsite	X		

chemistry or mineralogy of the raw material may be less important than its uniformity or its performance in the finished product. Marketing and research and development are often critical to the economic viability of an industrial-mineral prospect. Unlike most metals, for which there are well established markets and end uses, industrial minerals must often create their own markets by demonstrating a clear superiority in performance and, ultimately, cost over competing materials or sources.

In Oregon, a wide variety of industrial minerals is produced for regional, national, and international markets. The state's estimated total value of non-fuel mineral production in 1988 was \$169 million, of which virtually all was from industrial minerals. Sand, gravel, and crushed rock accounted for approximately \$115 million. Current producers are shown in Figure 1, and documented occurrences, past production, and present production of various industrial minerals are summarized in Table 1.

## AGGREGATES

Aggregate materials are produced by private companies and various federal, state, and county agencies. Crushed stone, almost exclusively basalt, is produced in all 36 counties (Figure 2); sand and gravel is produced in all but five counties; and volcanic cinders are produced in eight counties for construction uses and for ice control on highways. Production methods include open pits, quarries, and floating dredges. Areas of high demand and production are areas of high population, and urbanization continues to encroach on aggregate sources. Some areas do not have adequate known reserves, particularly for concrete aggregate where critical specifications must be met. In the past, small amounts of material have been imported for concrete aggregate when transportation costs were favorable. Off-shore sand and gravel resources have been identified, but as yet they have not been fully evaluated.



Figure 2. *Hard-rock quarry operation of Bayview Transit Mix, Inc., near Seaside in Clatsop County, producing crushed rock for road construction. The newly developed operation was honored with the 1988 Outstanding Operator Award of the Oregon Department of Geology and Mineral Industries, Mined Land Reclamation Program.*

## COMMON CLAY

Common clay is produced in 11 counties for engineering applications, for cement manufacture, and for brick production. Columbia Brick Works, Inc., at Gresham near Portland in Multnomah County, operates a high-volume facing brick plant utilizing clay mined on its property. Klamath Falls Brick and Tile Company in Klamath Falls (Figure 3) is a smaller, specialty-brick company producing a wide variety of colors of facing and paving bricks from clays mined in Klamath County and several other western counties.



Figure 3. *Klamath Falls Brick and Tile Company in Klamath Falls, Klamath County.*

## LIMESTONE

Limestone crops out in the northeastern counties, the southwestern counties, and, to a lesser extent, in some northwestern counties of the state. Historically, these deposits have been utilized for agricultural lime, dimension stone (Figure 4), cement production, and the production of calcium carbide.

Limestone and shale are quarried near Durkee in Baker County by Ash Grove Cement West. The shale and some of the limestone is used to manufacture portland cement which is marketed in Idaho, Oregon, and Washington.

Higher purity limestone from the same quarry is crushed and screened to various sizes and sold as sugar rock, that is, rock used in sugar-beet refining. Sugar-beet refiners calcine (fire) the limestone to quicklime which is then added to the sugar solution during processing to precipitate phosphatic and organic impurities. The lime is then precipitated by bubbling carbon dioxide (recovered from the calcining operation) through the sugar solution to form calcium carbonate, and the sugar solution is clarified by filtration. Sugar rock is sold to refiners in Idaho and eastern Oregon.

The combined value of portland cement and sugar rock from the Durkee operation has been about \$25 million each year for the last five years. Ash Grove also operates a lime kiln in the Portland area, but its feed stock is high-calcium limestone barged in from the company's quarry on Texada Island near Vancouver, British Columbia.

Limestone is also produced from two quarries in southwestern Oregon. D and D Ag Lime and Rock Company produces a small amount of agricultural limestone southeast of Roseburg in Douglas County. Campman Calcite Com-



Figure 4. Entrance to Oregon Department of Agriculture building in Salem, built approximately 20 years ago and faced with limestone from deposits in Benton County.

pany has acquired the Jones marble deposit near Williams in Josephine County and is producing calcium carbonate products for agricultural and paper pulp uses.

A comprehensive study of limestone occurrences in the state prepared by Howard Brooks of the Oregon Department of Geology and Mineral Industries is currently in press (Brooks, 1989).

## PUMICE

Oregon has ranked first in pumice production in the U.S. for seven of the last eight years. According to U.S. Bureau of Mines statistics, Oregon pumice production during that period has remained at about 200,000 short tons per year, valued at about \$1.5 million per year. Pumice occurs in many counties, particularly in those east of the Cascade Range, but it is mined on a large scale only near the city of Bend in Deschutes County. Cascade Pumice and Central Oregon Pumice mine 15- to 40-ft-thick airfall-pumice beds with overburden ratios up to 1:1. Overburden is removed, stockpiled, and finally backfilled by pan scrapers, and the pumice is mined by front-end loaders. Pit-run pumice is stockpiled and air dried, then crushed and screened to various size ranges. The major end use for products from both companies is lightweight aggregate in poured concrete and in structural and decorative concrete

blocks. Both companies serve, by truck and by rail, markets in northern California, Oregon, Washington, and British Columbia. The market area for pumice as lightweight concrete aggregate will probably remain regional, limited by transportation costs and competing sources in Idaho and California.

Lesser amounts of pumice are sold for landscaping (Figure 5), roofing, floor sweep, pet litter, and horticultural soil mixes. Cascade Pumice is also marketing a small tonnage of 2- to 4-in. lump pumice mined in Klamath County for stone-washing jeans and other denim garments. This small segment of the pumice market is of high enough value to bear shipping costs to the midwestern and eastern parts of the country.

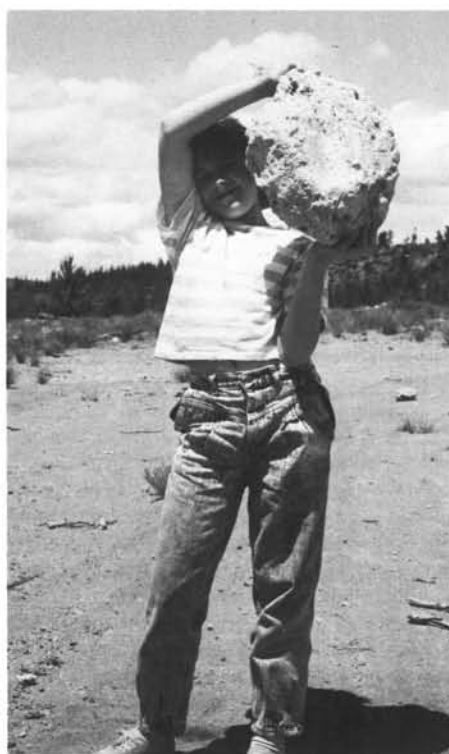


Figure 5. Pumice blocks such as the one easily held here by a child are used for landscaping purposes.

## CINDERS

Most volcanic cinder production in the state is used for road surfacing and for ice control, and most is produced by various government agencies. Neither Central Oregon Pumice nor Cascade Pumice sell to this particular market, but both mine red and black cinders for concrete-block aggregate, landscaping, and other uses. Cinder aggregate produces a heavier but higher strength block than pumice aggregate alone, and both may be blended for various strength and color characteristics. Landscaping products range from pea-sized grains up to boulders several feet in diameter.

## SILICA

Silica resources in Oregon include quartzofeldspathic sands and quartz replacement bodies. The sands include coastal dune sands, interior dune sands, onshore marine sands, and fluvial and lacustrine sands. The high-purity quartz bodies are the result of silicification of carbonate units and of rhyolitic volcanics. A reconnaissance survey of silica sources in the state is currently being conducted by the author.

Silica is produced by three companies, in one case from dune sands and in two from quartz bodies. CooSand Corporation mines quartzofeldspathic dune sands on the north shore of Coos Bay in Coos County. The deposit has a particle-size distribution ideal for glass manufacture and is located on a rail line. The sand is shipped to a plant near Portland where magnetic separation is used to lower the iron content sufficiently to meet specifications for container glass manufactured by Owens-Illinois in Portland. CooSand also sells some material for construction sand and for engine traction sand. Beneficiation testing, which includes scrubbing, froth flotation, and magnetic separation, has shown that some of the coastal dune deposits could be upgraded to meet flat-glass standards. The deposits are also well situated for rail or barge transportation to domestic or offshore markets.

Bristol Silica and Limestone Company, near Gold Hill in Jackson County (Figure 6), produces crushed and screened quartz in various size ranges for filter beds, poultry grit, landscaping, and exposed-aggregate concrete panels. The quartz body was formed by replacement of a carbonate lens, and in the past the company has also produced limestone and dolomite products from unaltered portions of the deposit. Bristol has been in production at this location for over 50 years.

Crushed quartz is also produced from Quartz Mountain, a silicified rhyolite in eastern Douglas County. Formerly, all production went to Hanna Nickel Company at Riddle, Oregon, for use in nickel smelting. Glenbrook Nickel, the new operator of the Nickel Mountain property, also uses this same source for silica. The owners of Quartz Mountain are seeking additional markets for their high-purity quartz.



Figure 6. Part of Bristol Silica and Limestone Company operation in Jackson County.



## SLAG

During its smelting of nickel at the Nickel Mountain property in Douglas County, Hanna Nickel produced several million tons of granulated slag. Part of the slag was purchased by Reed Minerals and stockpiled in Riddle. Reed crushes and sizes the slag into several grades of air-blast abrasives, which are marketed under the Green Diamond brand name. The abrasive products have the advantage of high durability and absence of free silica, and they are marketed primarily to West Coast shipyards and steel-tank manufacturing and maintenance companies.

## EMERY

Oregon Emery Company in Halsey, Linn County, produces abrasive and wear-resistant products from an emery deposit in eastern Linn County (Figure 7). The corundum-spinel-mullite-magnetite emery is apparently the result of contact metamorphism of ferruginous bauxites and is one of several such deposits owned by the company in the Cascade Range. Processing includes crushing and screening to produce specific particle shapes and size ranges. Oregon emery is used primarily in skid-resistant and hardened surfaces with concrete or epoxy systems in such areas as industrial floors, ramps, and traffic ways and on steel-bridge decking.



Figure 7. Emery outcrop in Douglas County deposit currently held under claim by Oregon Emery Company.

## DIATOMITE

Central and eastern Oregon have had a long history of lacustrine environments and silicic volcanism, which resulted in numerous occurrences of fresh-water diatomite beds. Two companies currently are mining and processing diatomite in Oregon: Oil-Dri Corporation of America, at Christmas Valley in Lake County, and Eagle-Picher Minerals, in northern Harney and Malheur Counties.

Oil-Dri produces crushed and screened granules for floor absorbents and cat litter for several distributors as well as for the company's own brand name products. Eagle-Picher trucks diatomite ore from mines near Juntura (Figure 8) to its plant near Vale where the diatomite is crushed, dried, flux-calcined, and sized for filter-aid products. The robust skeleton of the



Figure 8. View of Eagle-Picher diatomite mine (center of photo) in northeastern Harney County.

dominant diatom species in this deposit is particularly well suited to high-pressure and high-volume filtration of a wide range of mineral oils, edible oils, juices, beverages, and food products (Figure 9).

## PERLITE

Miocene silicic volcanism also formed perlite deposits in eastern Oregon. Some have been mined in the past, others have been drilled, and one, on Dooley Mountain in Baker County, is currently being mined by Supreme Perlite Company. Supreme Perlite has an expansion facility in Portland that processes raw perlite from Oregon and New Mexico to produce cryogenic, horticultural, masonry, and construction products.

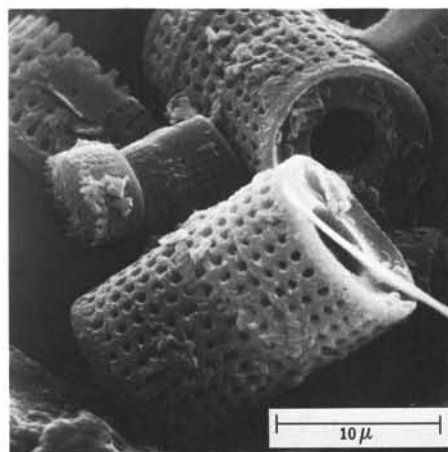


Figure 9. Scanning electron photomicrograph of diatoms. ( $\mu$  = micron = one-millionth meter. One inch has 25,400 microns.

A perlite deposit on Tucker Hill in southern Lake County has been drilled and evaluated by several companies. Although reportedly of commercial quality and quantity, the deposit is not well located with respect to market areas, and no development has yet been started.

## BENTONITE CLAYS

Sodium and calcium montmorillonite clays, generally known as swelling and nonswelling bentonites, respectively, occur throughout the volcanoclastic sediments in eastern Oregon (Figure 10). A reconnaissance survey of occurrences was recently completed by Gray, Geitgey, and Baxter (1988) of the Oregon Department of Geology and Mineral Industries. Preliminary testing suggests that these clays have potential for civil engineering, foundry, drilling, filler, binding, and absorbent applications.

Two companies are currently producing bentonite: Central Oregon Bentonite, 40 mi southeast of Prineville in Crook County, and Teague Mineral Products in Adrian in Malheur County. The principal market for swelling bentonite from both operations has been in engineering uses, including sealants for ponds, ditches, building foundations, and waste disposal sites.

## ZEOLITE

Bedded deposits of several zeolite minerals including clinoptilolite, chabazite, mordenite, erionite, and phillipsite have been documented in eastern Oregon. Several deposits are held by various companies, and many have been drilled and evaluated, including occurrences in the Harney Basin in Harney County; the Durkee



Basin in Baker County; and the "Rome Beds," the Sucker Creek Formation, and the Sheaville area in Malheur County. These localities all have zeolites of sufficient accessibility, thickness, areal extent, cation-exchange capacity, and absorption characteristics to be of economic interest, but, as with natural zeolites in general, large-volume markets remain elusive. Only Teague Mineral Products is currently producing zeolite in Oregon. Teague mines clinoptilolite from the Sucker Creek Formation in Malheur County and processes it at a mill in Adrian for absorbent and odor-control products. The mineral has also produced favorable test results in preventing uptake of radioactive cesium by plants in contaminated soils on Bikini Atoll and in removing heavy metals from mine drainage waters.

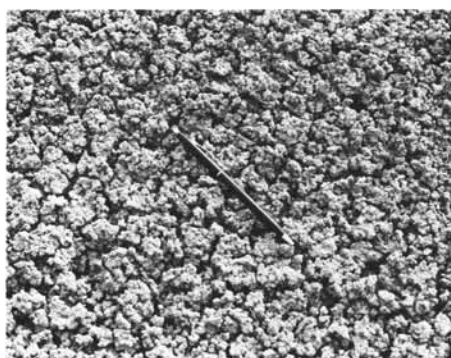


Figure 10. "Popcorn" weathering is often the first surface telltale for a deposit of swelling bentonite. Photo is of an outcrop near Dayville, Grant County.

## TALC

Ultramafic rocks crop out in northeastern and southwestern Oregon. Alteration of serpentinite bodies in these areas has produced talc and talc carbonate (dolomite or magnesite) deposits that may be of commercial importance. Amphiboles are present in some occurrences, but others are free of both amphiboles and chrysotile. Ferns and Ramp of the Oregon Department of Geology and Mineral Industries have recently reported on talc occurrences in the state (Ferns and Ramp, 1988).

Talc, or soapstone, is being produced by Steatite of Southern Oregon from deposits on Elliott Creek Ridge at the southern edge of Jackson County (Figure 11). The company's principal product is asbestos-free art sculpture stone in a variety of colors for domestic and international markets. Recently, the company has also begun to supply dimensional blocks and crushed material for heat-storage liners in ovens and fireplaces.

## GEMSTONES

Gem and lapidary material has been produced from Oregon for many decades, but, as is typical in most areas, it is very difficult to estimate accurately an annual value of production. Material is mined from lode claims, placer



Figure 11. Talc outcrop in Jackson County deposit mined by Steatite of Southern Oregon.

claims, private land, and free sites on federal land. Several varieties of agate are valued for their colors, banding, inclusions, and graphic patterns, and are often associated with areas of young volcanism and silicification. Specimens of petrified wood often show unusually well-preserved cell structure. One of the most highly prized materials is the thunder egg, a type of nodule or geode formed in silicic volcanics, particularly ash-flow tuffs. Thunder eggs may be filled with quartz crystals or with banded or patterned opal or chalcedony. Several varieties of opal, including a small amount of very high quality precious opal, are mined at Opal Butte in Morrow County.

Oregon sunstone, a faceting-grade, gemmy, calcic plagioclase feldspar, is mined near the Rabbit Hills in Lake County and in southeastern and northwestern Harney County (Figures 12 and 13). The sunstones occur in basalt flows as transparent megacrysts up to 3 in. long with compositions ranging from about Ab<sub>40</sub>An<sub>60</sub> to



Figure 12. Information marker at public collecting area for sunstones near Rabbit Hills in Lake County.

Ab<sub>25</sub>An<sub>75</sub>. Colors range from clear to pale yellow, pink, red, green, and blue, with increasing copper content. Some specimens exhibit aventurescence or schiller due to exsolved platelets of metallic copper. Current retail prices range from about \$20 to \$150 per carat, with the higher prices commanded by deeper colors, larger stones, or more elaborate cuts.

## PAST PRODUCTION

Many industrial minerals produced in Oregon in the past are no longer mined. Some, such as chromite, were mined in small tonnages and only as a result of wartime shortages. Others, including building stone and brick clays, were victims of shifts in architectural tastes and changes in construction techniques with the increased availability of portland cement. Production ceased for most in response to changing market conditions and increases in mining costs rather than because of noncompetitive product quality or the lack of reserves. Many of the industrial minerals listed in Table 1 as having had past production merit reevaluation with respect to new mining, beneficiation, and transportation methods and with respect to changes in demographics and in domestic and offshore markets. Three examples are given below.

(1) Historically, over 60 brick and tile plants have existed in Oregon, as shown in Figure 14. Many were small, local operations meeting immediate needs for construction materials and field tile. The number of active operations has dwindled to only two, but now there appears to be an increasing market for bricks in the Northwest. The larger volume producers were located in the far western quarter of the state, and this area still is highest in concentration of population and fuel, electric power, and transportation facilities. Most of the clays were simply dug as needed, and few deposits were drilled and evaluated ahead of production. The light firing clays in the area around McMinnville, Grand Ronde, and Willamina in Yamhill County are of particular interest, since yellow, buff, and white bricks were produced from those deposits.

(2) Currently, no building stone quarries in Oregon are continuously active, although there have been numerous operations in the past as



Figure 13. Collectors in the field at sunstone area in Harney County. Area is very similar to the one shown in Figure 12 but is not open to the public.

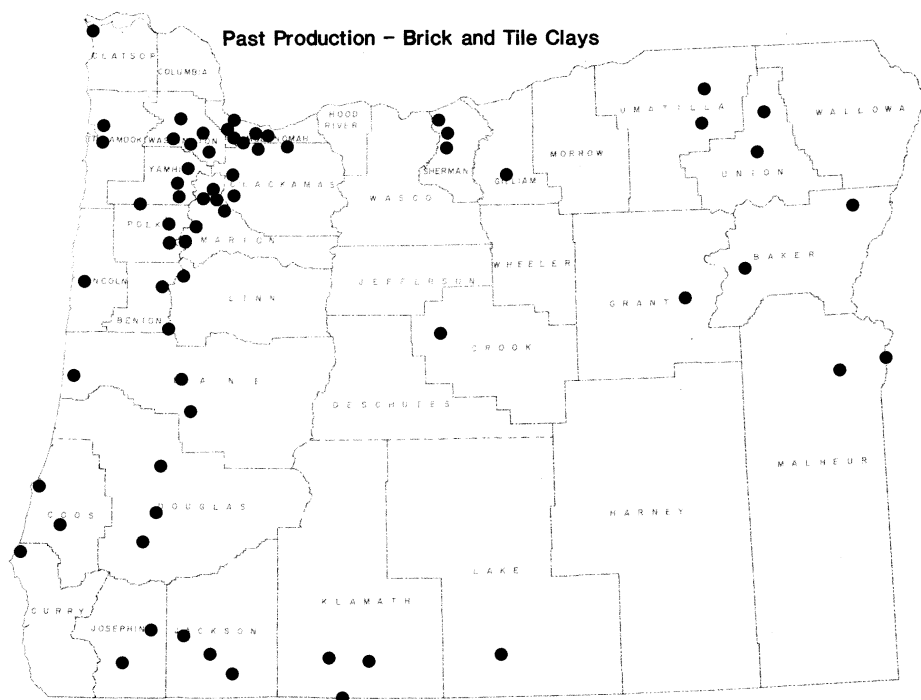


Figure 14. Location map of past production of brick and tile clays in Oregon.

shown in Figure 15. At the turn of the century, many dimension-stone quarries provided structural, decorative, and monumental stone for local and regional markets, including Portland and San Francisco. Rock types included buff to yellow sandstone, gray granites, white and black marbles, and variegated volcanic tuffs. Many quarries closed due to changes in architectural style, changes in construction techniques, and high costs of transportation from what were at that time remote locations. By mid-century, only highly colored and figured volcanic tuffs were being produced for decorative facing stone. The quality of many of the marbles, granites and tuffs is high, and with modern quarry methods and transportation they could again be marketable.

(3) Borates were mined from two locations at the turn of the century. Small pods of priceite in ultramafic rocks were mined in Curry County north of Brookings, and surface efflorescences were processed at Borax Lake in the Alvord Valley of southern Harney County—until more accessible deposits were discovered in California. It is unlikely that the Curry County occurrence could ever be economic, and shallow drilling has been unproductive in Harney County. However, the possibility of borates in the Alvord Valley at depths exploitable by solution mining remains untested.

#### DOCUMENTED OCCURRENCES

Table 1 also lists documented occurrences of industrial minerals that have not been produced in the state. Many have been documented only by brief, unpublished reports, and their potential is difficult to assess. For example, little information is available about an occurrence of massive garnet on Antelope Peak in

Baker County, a wollastonite occurrence on Foster Creek in Douglas County, or nepheline syenite on Table Mountain and other peaks in Lincoln County. Others, such as the ferruginous bauxites in northwestern Oregon and kaolin on Hobart Butte in Lake County, have been studied in detail but are not amenable to processing approaches currently used in the United States.

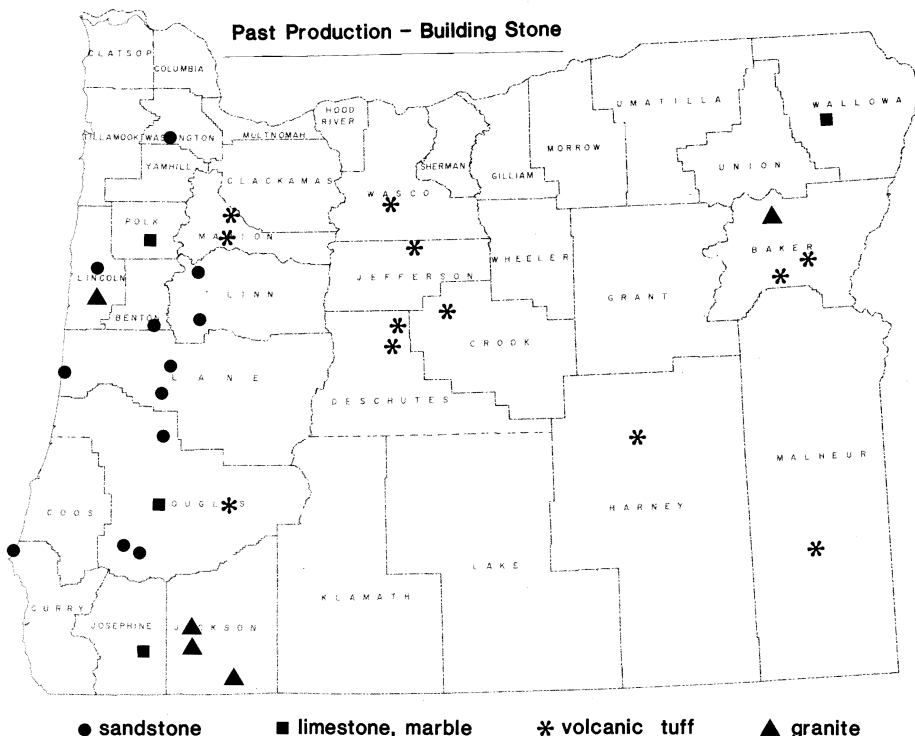


Figure 15. Location map of past production of building stone in Oregon.

#### SOURCES OF INFORMATION

By far the most comprehensive source of information on industrial minerals is the latest edition of *Industrial Minerals and Rocks*, published by the Society of Mining Engineers (Lefond and others, 1983). This and earlier editions describe the geology, exploration, production, uses, and specifications of a wide range of industrial minerals.

Information on specific industrial minerals is also included in two publications of the U.S. Bureau of Mines: the annual *Minerals Yearbook*, which contains summaries and statistical data (U.S. Bureau of Mines, 1989); and the reference work *Mineral Facts and Problems*, which reviews the geology, production, and uses for various mineral commodities (U.S. Bureau of Mines, 1985).

Still a very useful text is *Geology of the Industrial Rocks and Minerals* (Bates, 1960), which discusses industrial minerals in the context of the geologic settings of their occurrences. The book *Geology of the Nonmetallics* (Harben and Bates, 1984) gives a worldwide perspective on industrial mineral deposits and production. Current information is best obtained from *Industrial Minerals*, a monthly publication that contains short summaries on worldwide industrial mineral activity, detailed articles on specific commodities or regions, and current market prices for various industrial minerals.

The Oregon Department of Geology and Mineral Industries has published a total of nine bibliographies of the geology and mineral resources of the state, the latest supplement ex-

(Continued on next page)

## Recently excavated mammoth tusk on display in Prineville BLM office

A mammoth tusk found eroding from a stream bank near Mitchell in May 1988 by Merle, Sandra, and Devin Simmons of Eugene (see cover photo) has been placed on prominent display in the lobby of the Prineville District Office of the U.S. Bureau of Land Management (BLM). Merle, a dental technologist, suspected that the rather strange looking white material was ivory from a tooth and alerted the John Day Fossil Beds National Monument. The staff there passed a sample and the information from Simmons along to BLM. Through an interagency agreement, the Park Service helped protect the tusk by applying glues to the weathered specimen and patrolling the location until the tusk could be excavated by paleontologist Dave Taylor of the Northwest Natural History Association.

According to Taylor, the tusk is a greatly enlarged incisor tooth that most likely belonged to the columbian mammoth, or *Mammuthus columbi*. The columbian mammoth was large, even for an elephant, attaining a height of up to 13 ft at the shoulders. It was common during late Pleistocene time and ranged throughout North and Central America.

BLM archaeologist Suzanne Crowley Thomas stated that the tusk, which was found in stream gravels with its tip lodged against a large boulder, was all that was left of a carcass that had probably washed downstream long ago.

The tusk was found on land in Wheeler County that was recently acquired by BLM in the Sutton Mountain land exchange. The area is known to be rich in paleontological resources dated 34 to 54 million years old. This find is unique, however, because it is so recent.

Before the tusk could be excavated, 6 ft of earth had to be removed from above the fossil, and space to work had to be cut into the steep hillside. Taylor, who led the excavation one hot weekend in August 1988, was assisted in the process by archaeologist Thomas and volunteers Bob Tavernia, Scott Thomas, and Merle and Sandra Simmons.

The tusk was exposed, and plaster-soaked burlap strips were applied to form a protective jacket. Boards were added to stabilize the tusk, and finally the whole package was lifted onto a stretcher and carried downhill. The tusk then spent the next few months in a laboratory at Portland State University, while Taylor cut and peeled away the plaster jacket, applied more glues, and filled in some of the missing surface with plaster.

After its return to central Oregon, the tusk was placed in a specially designed case in the lobby of the Prineville BLM District Office along with photographs and descriptions of the excavation. The Bridge Creek mammoth tusk exhibit is proving to be a popular attraction



Sandra Simmons helping in excavating the mammoth tusk she and her family found near Mitchell in 1988.

and has been viewed by several hundred visitors since its unveiling on April 19, 1989.

This tusk is a classic example of the way in which private citizens who make an important scientific discovery on public lands can report the find to the appropriate land managing agency or to a member of the professional community, thereby assuring that the discovery will be properly treated and preserved for all to study and enjoy.

The casual use and collection of fossils have long been recognized as legitimate activities on public lands. Some restrictions do exist, however, which provide for the management and protection of fossils of major scientific value. Generally, common invertebrate and plant fossils may be collected by private individuals without a permit. Exceptions can occur when the fossils are of high scientific value. Vertebrate fossils generally may be collected under permits issued by BLM or other appropriate authorities, and these permits are issued only to bona-fide scientific researchers and institutions.

Opportunities are available, however, for private individuals to participate in scientific field studies through volunteer work with active research organizations such as colleges, universities, conservation organizations, and museums. For those who want to participate, there is ample opportunity to dig and learn through these organized research programs.

*BLM News, Oregon and Washington*

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tending through 1984 (Neuendorf and Yost, 1987). The Department has a noncirculating library of current and out-of-print periodicals, theses and dissertations, and published and unpublished reports, including reports written for the War Office during World War II. The Department also maintains files of unpublished information on most of the commodities listed in Table 1. Summaries of these commodities were published in the Department's Bulletin 64, *Mineral and Water Resources of Oregon* (Weissenborn, 1969). Comprehensive Department studies on talc and bentonite have been published recently; a limestone survey is in press; a silica summary is in progress; and similar studies of other commodities are planned for future work.

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# Elemental composition of the very heavy nonmagnetic fraction of Pacific Northwest beach sands

by Stephen E. Binney and Bilgees Azim, Department of Nuclear Engineering; and Curt D. Peterson, College of Oceanography, Oregon State University, Corvallis, Oregon 97331

## ABSTRACT

Sieving, magnetic separation, and gravimetric separation were used to isolate the very heavy nonmagnetic (VHNM) fraction (specific gravity [sp gr] > 4.2) of a suite of Pacific Northwest beach samples. The VHNM samples were then analyzed by instrumental neutron activation analysis to detect the elemental concentrations present. Zirconium (Zr) and titanium (Ti) were the two most prominent elements observed, with Zr (as zircon) generally increasing and Ti (as rutile) generally decreasing from south to north. The zircon plus rutile concentrations were in the range of about 72 to 100 percent (mean and standard deviation of  $91.7 \pm 8.2$  percent) of the VHNM mass. Several other elements were closely correlated with the major elements Zr and Ti.

## INTRODUCTION

The very heavy nonmagnetic (VHNM) fractions (sp gr > 4.2) of a suite of Pacific Northwest beach samples were analyzed to determine their elemental compositions. These data could be used along with other data to estimate the economic mineral content of the VHNM fraction of offshore sands. Recent measurements of the elemental content of coastal placers along the northern California, Oregon, and Washington beaches have concentrated on

the heavy (sp gr > 3.0) magnetic fraction (Peterson and Binney, 1988) and the VHNM fraction (Azim, 1988) of these placers. This paper discusses the analysis of the VHNM fraction of samples collected from 14 beaches in this area. The study was originally designed to focus primarily on zircon, although the presence of rutile in the VHNM fraction expanded this scope somewhat.

In the Klamath Mountain source area (provenance) of southern Oregon and northern California, zircon is derived from a variety of igneous and metamorphic rocks. These primary source rocks range from Pre-Triassic to Late Jurassic in age and are distributed throughout the Klamath Mountain provenance (Irwin, 1960). Tertiary sedimentary rocks, derived in part from the Klamath Mountain terrane and from Rocky Mountain terranes to the east, might also supply second-cycle zircon to Oregon Coast Range drainages. Kulm and others (1968) report that the abundance of zircon varies from 1 to 13 percent in heavy-mineral assemblages (sp gr > 3.0) of the Klamath Mountain and Oregon Coast Range rivers.

## SAMPLE DESCRIPTION AND PREPARATION

The beach samples that were analyzed were chosen to span a wide geographic and geological range along the northern Pacific coast of the United States (Figure 1). Bulk samples were collected in March 1984 at mid-beach face sites on the southern side of headlands. Samples were taken down to 2 m below the winter-beach surface to obtain concentrated placer compositions at depth (Peterson and others, 1986).

The first step in the sample separation process involved sieving about 100 g of the beach sand (0 to 2.5  $\phi$  at 0.25- $\phi$  intervals) to separate rock fragments and other larger particles from the remainder of the sample. All the particles coarser than 2.25  $\phi$  were discarded, leaving the fine grains consisting of relatively heavy particles.

The major steps (Figure 2) in preparing the sieved samples for analysis are as follows:

1. Removal of the light minerals from the heavy minerals at a sp gr of 3.0 by the use of sodium polytungstate.

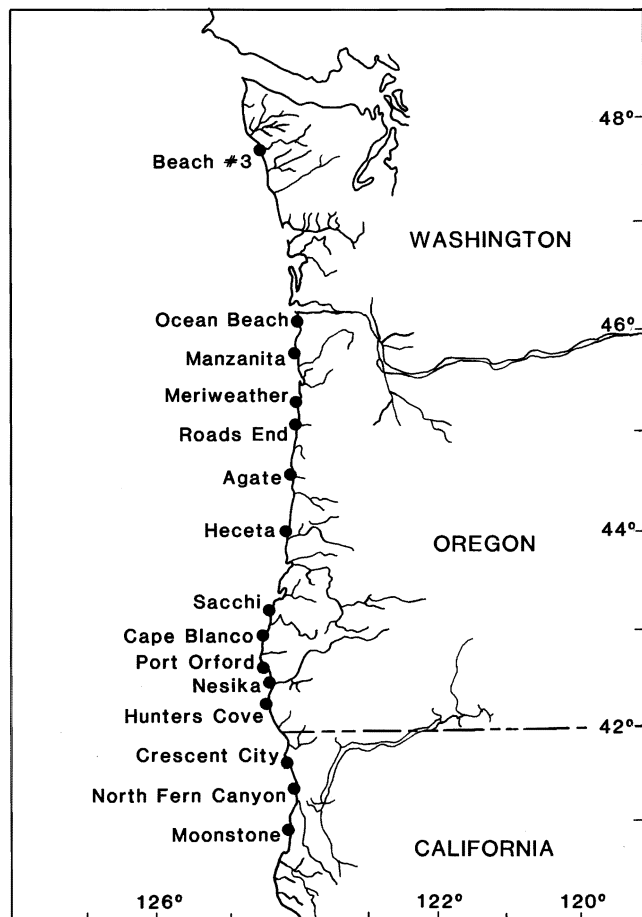


Figure 1. Location of beach sample collection sites on Pacific Northwest beaches.

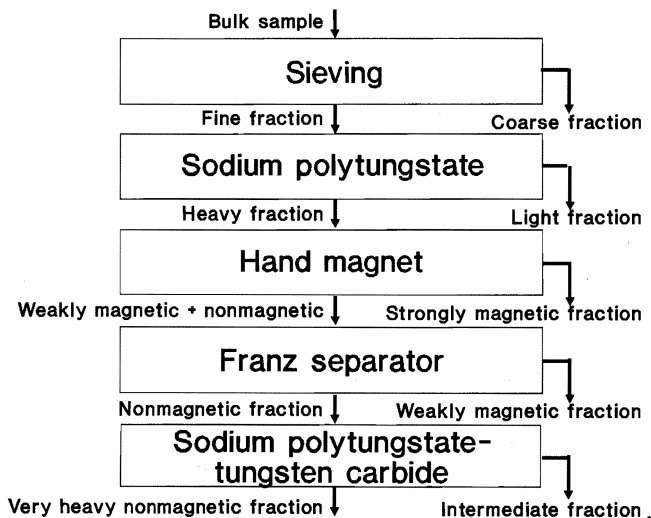


Figure 2. Schematic of bulk beach sample separation procedure.



2. Removal of the heavy magnetic minerals from the nonmagnetic heavy minerals by the use of a hand magnet and a Frantz magnetic separator.

3. Removal of the intermediate minerals from the VHNM minerals at a sp gr of 4.2 by the use of a tungsten carbide-sodium polytungstate mixture.

The purpose of the sodium polytungstate separation was to achieve a separation of the fine fraction at a sp gr  $\leq 3.0$ , e.g., removal of the light minerals such as quartz and feldspar. The sample was stirred into the solution and allowed to settle for about 12 hours. Once separation had occurred, the light minerals were isolated by carefully immersing the beaker of solution into liquid nitrogen. The lighter particles were decanted, and the heavier particles, after thawing, were thoroughly washed in a filter to avoid Na and W contamination. After washing, the heavy fraction was dried in an oven at 80 °C for 12 hours (or overnight).

The magnetic separation process removed the magnetic fraction of the sample. A hand magnet was used first for the removal of strongly magnetic substances such as magnetite. This method was efficient and averted subsequent clogging in the Frantz isodynamic magnetic separator, in which standard settings were used for a more complete separation of the magnetic and nonmagnetic fractions.

After the Frantz separation, a mixture of tungsten carbide and sodium polytungstate was used to separate the VHNM fraction from the less dense nonmagnetic fraction. Zircon and rutile resided in the VHNM fraction (sp gr 4.6-4.7 and 4.2-4.3, respectively).

After the separation process was completed, the VHNM fraction was examined under a microscope using a standard petrographic analysis method (Phillips and Griffen, 1981) and was found to consist mainly of translucent nonisometric minerals and trace amounts of opaque minerals. The VHNM samples were then weighed and heat sealed with a quartz rod into clean 227-dram vials for analysis.

## METHOD OF ANALYSIS

Sequential instrumental neutron activation analysis (INAA) was used to analyze the VHNM samples and determine elemental concentrations (Laul, 1979). Four reference standards were used: fly-ash powder (NBS 1633a), Columbia River Basalt Group powder (CRB3), a liquid U standard, and a liquid Zr standard. The CRB3 standard is an Oregon State University (OSU) standard that has been calibrated with the USGS BCR-1 standard rock. The VHNM irradiation samples had masses in the range of 20 to 160 mg, although one sample had a mass of  $< 10$  mg (all that was available). The samples and the standards were irradiated under identical conditions in the OSU TRIGA Reactor. The reactor was operated at a power level of 1 MW, corresponding to a thermal neutron flux of  $1 \times 10^{13}$  n/cm<sup>2</sup>-s in the pneumatic transfer system (for the short irradiations) and  $3 \times 10^{12}$  n/cm<sup>2</sup>-s in the rotating rack (for the long irradiations).

For short irradiations, the samples were irradiated for two minutes and then allowed to decay for 10 minutes. The short-lived nuclides (representative of the elements Ti, Al, V, Mg, and Ca) were analyzed first for five minutes. After two to five hours, the samples were reanalyzed for 10 minutes to determine the elemental contents of Dy, Na, K, and Mn.

For the long irradiation, the samples and the standards were irradiated for seven hours. After a decay period of seven to 14 days, the samples were analyzed for three hours to determine the elemental concentrations of Fe, Co, As, Sb, Rb, Ba, La, Nd, Sm, Yb, Lu, W, and Np (representative of U). The samples were allowed to decay for an additional 20 to 30 days and then analyzed for six hours to measure the concentrations of Sc, Cr, Co, Zn, Se, Sr, Sb, Cs, Ce, Eu, Tb, Zr, Hf, Ta, and Pa (representative of Th).

The data were collected using a p-type Princeton Gamma Tech Ge(Li) detector with a 13-percent efficiency (relative to a 7.62-cm

by 7.62-cm NaI [Ti] detector at 1,332 keV) and a peak to Compton ratio of 47:1 at 1,332 keV. Dead times did not exceed 10 percent for any of the samples.

## RESULTS

Results are referenced to the VHNM fraction sample masses, i.e., concentrations are expressed in parts per million (ppm) as  $\mu\text{g}$  of element per g of VHNM sample. Table 1 shows the concentrations (as ppm) of the major, minor, and trace elements in the VHNM samples.

Zirconium was the most prominent element measured (INAA is not very sensitive to O or Si), with its abundance ranging from about 17 to 47 percent by weight (as the element Zr). The highest concentration of Zr (47.2 percent) occurred at Agate Beach (latitude = 44.67° N.). (Note: the maximum possible Zr concentration is 49.6 percent, the weight percentage of Zr in zircon.) Figure 3 shows the variation of Elemental Zr concentration as a function of latitude.

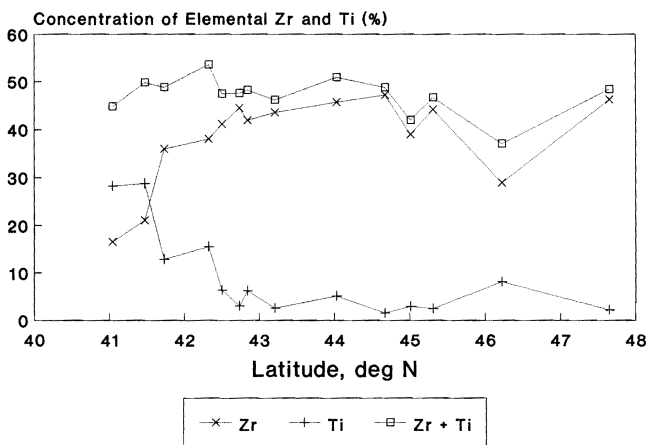


Figure 3. Zirconium and titanium concentrations in the VHNM fraction of beach samples.

Titanium was the second most prominent element in the VHNM samples, with an elemental concentration ranging from about 2 to 29 percent. The highest concentrations of Ti occurred at the four southernmost beaches (northern California and southern Oregon). For the rest of the samples, the Ti concentration was less than about 8 percent of the VHNM sample mass, although Ocean Beach had a relatively higher concentration of Ti and a correspondingly lower Zr concentration than neighboring beaches. Figure 3 also shows the variation of Ti concentration as a function of latitude. Hafnium, which is always present with Zr in nature, closely followed the concentration trend of Zr in the VHNM samples. The concentration range of Hf was about 0.4 to 1 percent. The ratio of the concentration of Hf to the concentration of Zr + Hf varied only slightly, from 2.02 to 2.24 percent, with a mean and standard deviation of 2.13 and 0.08 percent, respectively.

The other elements that occurred as major elements in the VHNM samples were Al, Ca, Ba, and Mg. Aluminum occurred in the range of about 0.3 to 6.5 percent. Calcium had a concentration range of 0.2 to 2.5 percent in 11 of the 14 samples. Concentrations of barium varied widely, and it appeared as a major, minor, or trace element in the various VHNM samples. Although Mg was present in the VHNM samples, accurate amounts could not be determined because it was discovered after the analyses that the Mg standard had chemically decomposed; hence Mg values are not reported.

Vanadium occurred as a trace element in the VHNM samples, with concentrations ranging from 50 to 655 ppm. Uranium and Th were also present in the samples as trace elements with maximum

Table 1. Elemental composition of the VHNM samples (ppm)

Sample	Lat.	Ti	Al	Ca	V	Mn	Na	K	Dy	Fe	Co	Rb	Ba	La
Moonstone	41.04	282359	8834	19864	664	0.0069	0.013	<0.90	44	0.8	<5.5	<88	21040	11
North Fern Canyon	41.47	287461	1964	4811	661	0.0018	0.020	<0.01	32	0.4	2.0	<11	1899	6
Crescent City	41.73	128864	7211	7828	175	0.0030	0.041	<0.08	59	0.2	<1.4	<10	<350	<0.1
Hunters Cove	42.32	155472	5568	6825	309	0.0041	0.033	<0.13	55	0.3	4.4	<18	16650	26
Nesika	42.50	63797	4768	7897	112	0.0043	0.071	0.02	71	0.2	4.2	<26	540	<0.2
Port Orford	42.73	30347	2880	2384	66	0.0010	0.009	<0.05	75	0.2	1.5	<7	5598	28
Cape Blanco	42.84	62526	9653	8067	138	0.0035	0.040	<0.12	74	<0.2	<2.0	<9	8536	18
Sacci	43.21	25585	2851	925	65	0.0010	0.012	0.05	75	<0.1	<0.9	<8	<370	25
Heceta	44.03	51573	5762	<500	130	0.0017	0.023	<0.05	96	<0.2	<2.3	<11	<500	29
Agate	44.67	15574	9401	<500	52	0.0012	0.012	<0.05	92	<0.1	<1.5	<8	<390	31
Roads End	45.01	29561	64962	8782	120	0.0041	0.047	<0.17	78	<0.2	<2.1	<16	2828	28
Meriweather	45.31	24615	5273	2007	79	0.0021	0.010	<0.05	80	0.2	<1.0	<9	<420	41
Ocean Beach	46.22	81349	56351	24879	277	0.0064	0.057	<0.17	91	<0.1	<0.3	<35	<410	<0.4
Beach #3	47.65	21774	1973	3678	56	0.0019	0.012	<0.05	74	<0.1	<1.2	<7	1463	27

Sample	Lat.	Sm	Yb	Lu	U	Sc	Cr	Zn	Sb	Cs	Ce	Eu	Tb	Zr	Hf	Th	Se
Moonstone	41.04	13	109	26	138	75	172	<67	<4	<5	800	2	5	165500	3659	82	<37
North Fern Canyon	41.47	10	113	23	121	39	343	<13	1	<1	8	1	4	210700	4673	132	55
Crescent City	41.73	5	1	<0.3	<1	77	153	**	1	<1	50	1	5	359400	7409	149	**
Hunters Cove	42.32	23	219	44	251	73	320	263	3	<2	30	2	8	380300	8385	148	28
Nesika	42.50	<1	<2	<0.3	<4	71	77	<3	<1	<2	148	2	6	411100	8932	364	<3
Port Orford	42.73	26	277	52	338	71	<64	**	1	<1	*	2	6	445300	9307	175	**
Cape Blanco	42.84	23	245	48	297	67	88	302	2	<1	35	2	10	419400	9606	183	43
Sacci	43.21	27	283	53	344	64	<74	**	1	<1	*	1	6	436000	9191	170	**
Heceta	44.03	34	298	57	398	68	93	244	2	2	58	2	12	457100	10410	215	43
Agate	44.67	29	308	58	386	68	<65	**	<1	<1	67	1	7	472200	9805	219	**
Roads End	45.01	30	245	47	306	57	73	192	2	<1	90	3	11	390300	8891	172	<2
Meriweather	45.31	35	328	61	426	64	167	**	1	<1	*	1	7	442400	9199	203	**
Ocean Beach	46.22	<1	<2	<0.3	<4	49	121	<41	4	<2	280	5	13	289800	6652	227	<29
Beach #3	47.65	29	279	55	351	79	<67	**	<1	<1	*	2	5	462800	9978	164	**

\* Total concentration was due to  $^{235}\text{U}$  fission.

\*\* Concentration could not be determined.

Underlined values are questionable, based on limited concentration of sample.

concentrations of several hundred parts per million. Uranium and Zr had a strong positive correlation coefficient (+0.937).

Lanthanide group elements La, Ce, Sm, Eu, Tb, Dy, Yb, and Lu were detected at trace levels, where the La and Ce concentrations were corrected for the contribution due to  $^{235}\text{U}$  fission products (Sm had a negligible contribution from  $^{235}\text{U}$  fission). Lanthanum, Sm, Yb, and Lu in the lanthanide group showed a similar concentration trend versus latitude, but the rest of the lanthanides showed no particular trend. Most of the rare earths in the VHNM samples followed the trend of the major element Zr.

Of the other elements in the VHNM samples, Sc and Cr occurred only as trace elements. Chromium concentrations were generally higher in the southernmost beaches. Other trace elements present in the VHNM samples were Zn, Sb, and Se. There was a very small amount of Fe (< 1 ppm) in the VHNM samples, as expected for the nonmagnetic fraction. Concentrations of Mn and Na were in the parts per billion range in all of the samples. Potassium, Cs, and Rb concentrations were below the detection limit in all or nearly all of the samples. The same was true for Co in most of the VHNM samples. The Nd values were unreliable and were not reported.

## DISCUSSION

The results in the previous section indicate that the sample-separation techniques employed specifically to separate the zircon from the bulk samples worked fairly well, although rutile was also present in the VHNM fraction. The zircon plus rutile concentrations (as determined by INAA results) were in the range of about 72 to 100 percent by weight. The degree of separation was further exemplified by the near absence of Fe (< 1 ppm), most of which was removed in the magnetic fraction. As an in-

dependent measurement, the VHNM sample from North Fern Canyon was analyzed qualitatively by X-ray diffraction; the result of this investigation clearly indicated the presence of rutile, thereby identifying the mineral form of the Ti observed by INAA.

A previous study by Peterson and Binney (1988) indicated that the concentration of Ti present (as ilmenite) in the four southernmost beaches was in the range of 1 to 10 percent of the magnetic fraction of the bulk sample. In this study, the VHNM samples analyzed were the nonmagnetic portions of the heavy fraction from the same beaches. Hence the presence of Ti (as rutile) in the VHNM samples contributes to a higher total Ti concentration in the beach sands of northern California and southern Oregon than was established by the authors in their previous work, although the VHNM sample masses were not an appreciable fraction of the bulk sample masses. Also, a comparison of the results for these northern California and southern Oregon beaches between this study and the Peterson and Binney (1988) study could possibly imply two different sources of Ti minerals (ilmenite and rutile), although additional studies are necessary to investigate the sources of the ilmenite and rutile.

As indicated earlier, the VHNM fraction of the bulk sample consisted mostly of the mineral zircon. The concentration of zircon (Table 2) was largest (7.56 percent of the heavy fraction) at Agate Beach (Figure 1). There is a generally increasing trend of zircon concentration from south to north between  $41^{\circ}\text{N}$ . and about  $43^{\circ}\text{N}$ . North of about  $43^{\circ}\text{N}$ ., the zircon concentration remains fairly constant in the VHNM fraction of the beach samples.

In Figure 3, the sum of the elemental Ti and Zr concentrations is plotted as a function of latitude; the sum of the concentration of the two elements in the VHNM fraction is rather constant (average value of  $47.2 \pm 4.0$  percent). The corresponding value is  $91.7 \pm 8.2$

Table 2. Weight percent of zircon and rutile in the VHNM and heavy fractions

Sample	VHNM fraction			Heavy fraction	
	Zircon	Rutile	Sum	Zircon	Rutile
Moonstone	33.3	47.2	80.5	0.01	0.01
North Fern Canyon	42.3	48.0	90.3	0.32	0.36
Crescent City	72.2	21.5	93.7	0.19	0.06
Hunters Cove	76.4	26.0	102.4	0.53	0.18
Nesika	82.6	10.7	93.3	0.13	0.02
Port Orford	89.5	5.1	94.6	6.46	0.37
Cape Blanco	84.3	10.4	94.7	2.27	0.28
Sacci	87.6	4.3	91.9	4.56	0.22
Heceta	91.9	8.6	100.5	0.93	0.09
Agate	94.9	2.6	97.5	7.56	0.21
Roads End	78.5	4.9	83.4	0.34	0.02
Meriweather	88.9	4.1	93.0	4.65	0.22
Ocean Beach	58.2	13.6	71.8	0.33	0.08
Beach #3	93.0	3.6	96.6	0.82	0.03

percent when expressed as the mineral (zircon plus rutile) weight percent. Hence the Ti plus Zr concentrations in the VHNM samples vary less than 10 percent (1  $\sigma$ ) over a distance of more than 700 km along the Pacific coastline from northern California to central Washington and comprise nearly 100 percent of the VHNM sample.

A linear regression was performed between each pair of elements measured in the VHNM samples. The corresponding values of the correlation coefficient are shown in Table 3. The correlation coefficient for Ti and Zr was -0.911, which is a typical correlation for a predominantly binary mineral system.

As indicated earlier, the ratio of Zr to Hf is quite constant over the entire suite of samples, with Hf and Zr having a relatively high correlation coefficient (+0.986). In particular, the eight southernmost beaches, which are within the Klamath Mountain drainage, had a Zr/Hf ratio of  $46.1 \pm 1.6$ , while the six northernmost beaches (Coast Range drainages) showed no statistical difference in their Zr/Hf ratios ( $45.7 \pm 2.2$ ). This behavior is to be expected because of the similar chemical nature of Zr and Hf.

Most of the chromite in these beach sands was apparently combined in sand grains along with magnetite and hence was removed in the magnetic separation. Chromium had a moderately strong correlation with Ti (+0.708) in the VHNM samples. Although present only as a trace element, the higher Cr measurements in the

four southernmost beaches are consistent with previous measurements (Peterson and Binney, 1988) of higher chromite concentrations in the magnetic fraction of the samples from these same beaches. The trace element V was also strongly correlated (+0.974) to the major element Ti, with its highest concentration in the two southernmost beaches.

Uranium had a relatively strong correlation with Zr (+0.937). Some of the lanthanides followed a similar trend with Zr, e.g., La (+0.820), Sm (+0.748), Yb (+0.737), Lu (+0.964), and Dy (+0.717). Such relatively large correlation coefficients suggest the possibility that these trace elements could be used as tracers for zircon source studies.

Some anomalously low values were associated with some of the rare-earth concentrations (Ce, Nd, and Lu) in the VHNM samples from Crescent City, Nesika, and Ocean Beach. The U values were also questionable at these beaches. These anomalies have been attributed to the fact that (1) low gamma-ray energies were used for analysis of these elements and (2) the VHNM sample mass available was small (except for Crescent City), both of which produced large uncertainties in the results.

## SUMMARY

A separation scheme was devised to separate the VHNM fraction from the bulk beach sample that contained minerals of various magnetic susceptibilities and specific gravities. The VHNM samples were analyzed by sequential INAA to detect the elemental concentrations present.

Zircon was present as the major mineral in the VHNM samples, with a weight percent ranging from 58 percent to 95 percent for most of the samples. Samples from the southernmost beaches (northern California) contained an appreciable amount of rutile along with the zircon. The zircon and rutile served to substantiate the previously known economic importance of the Pacific Northwest beach and continental-shelf sands (Kulm and Peterson, 1989).

## ACKNOWLEDGMENTS

Margaret Mumford, OSU College of Oceanography, provided valuable assistance during the sample-separation phase of this study, as well as the XRD analyses. Mike Conrady similarly assisted in the data collection and analysis at the OSU Radiation Center.

Table 3. Correlation coefficients for elements in the VHNM samples

	Al	Ca	V	Mn	Ni	Dy	Fe	Co	Ba	La	Sm	Yb	Lu	U	Sc	Cr	Zn	Se	Ce	Ru	Tb	Zr	Hf	Th
Ti	-0.1580	0.3697	0.9738	0.2863	-0.0206	-0.8671	0.8163	-0.1016	0.5163	-0.8279	-0.7772	-0.7461	-0.9485	-0.9349	-0.2517	0.7075	0.4168	0.4237	0.4665	-0.0172	-0.3687	-0.9111	-0.9084	-0.5238
Al		0.5695	-0.0242	0.5176	0.4934	0.3164	0.4834	0.9237	-0.1454	0.1152	0.1878	0.0375	-0.0147	-0.9325	-0.4412	-0.3997	-0.8156	-0.4102	0.0792	0.7661	0.6802	-0.1753	-0.0975	0.0699
Ca			0.4690	0.8723	0.4374	0.0422	0.8782	0.9312	0.6987	-0.5247	-0.4752	-0.5445	-0.6421	0.0040	-0.1776	-0.2630	-0.5105	-0.5610	0.7285	0.8157	0.4994	-0.6513	-0.5902	-0.0314
V				0.3362	-0.0395	-0.7849	0.8537	-0.1834	0.4973	-0.8266	-0.6727	-0.6382	-0.9555	-0.6477	-0.3794	0.6553	0.2652	0.5127	0.5440	0.1213	-0.2513	-0.9497	-0.9326	-0.5190
Mn					0.5305	-0.1471	0.5985	0.9972	0.6899	-0.2803	-0.3396	-0.4120	-0.4618	-0.4904	0.0041	-0.2142	-0.1701	-0.8291	0.6813	0.7096	0.2567	-0.5376	-0.4966	-0.0367
Ni						0.0748	-0.2975	0.7724	-0.3117	-0.1737	-0.2904	-0.4135	-0.1663	-0.1936	-0.1534	-0.4631	-0.2378	-0.5013	-0.1871	0.5063	0.4052	-0.1178	-0.0400	0.5829
Dy							-0.6830	0.1347	-0.3985	0.7987	0.8254	0.7654	0.9233	0.9388	0.1090	-0.7361	-0.2739	-0.2718	-0.2354	0.2798	0.6570	0.7166	0.7479	0.5373
Fe								-0.1579	0.7043	-0.7350	-0.4056	-0.3724	-0.7922	-0.7848	-0.0096	0.1667	0.0000	1.0000	0.8917	0.5312	-0.3976	-0.8884	-0.8803	-0.5883
Co									0.3999	0.2757	0.1833	0.0054	0.0912	-0.0480	0.4866	-0.5025	0.0000	-1.0000	0.5606	0.4591	0.6582	0.2383	0.3191	0.4765
Ba										-0.2115	-0.3694	-0.4264	-0.3559	-0.4211	0.3749	0.2632	0.5562	-1.0000	0.6492	0.2584	0.0299	-0.4783	-0.4705	-0.5666
La											0.9375	0.9210	0.9131	0.9159	0.3746	-0.3892	-0.8021	-0.7592	-0.3961	-0.1230	0.3627	0.8205	0.7771	0.7505
Sm												0.9625	0.9519	0.9644	0.0786	-0.4242	-0.6377	-0.4838	-0.2520	0.1845	0.5813	0.7484	0.7762	0.7424
Yb													0.9956	0.9923	0.0223	-0.3096	-0.1456	-0.4933	-0.2768	0.0735	0.4578	0.7374	0.7519	0.7308
Lu														0.9915	0.4253	-0.5543	-0.0638	-0.5339	-0.4926	-0.1859	0.4106	0.9636	0.9372	0.8697
U															0.3612	-0.5814	-0.2062	-0.3968	-0.4752	-0.2043	0.4265	0.9365	0.9103	0.8897
Sc																-0.2774	0.7100	-0.8652	0.2155	-0.2417	-0.2664	0.4057	0.3615	-0.0059
Cr																	0.2348	-0.0110	-0.1057	-0.3631	-0.5185	-0.4701	-0.5033	-0.5112
Zn																		0.1953	-0.9087	-0.8493	-0.4108	0.2032	0.1742	-0.0014
Se																			-0.3758	-0.7688	-0.4104	-0.5754	-0.5334	-0.1037
Ce																				0.3743	-0.1632	-0.6503	-0.6441	-0.3123
Ru																					0.6734	-0.2885	-0.1923	0.1266
Tb																						0.1830	0.3071	0.2616
Zr																							0.9861	0.4622
Hf																								0.4802

Nuclear reactor services and INAA detection equipment were provided by the Radiation Center. Sample collection and initial processing were carried out with support from the Oregon State University Sea Grant Program, under Grants No. NA81AA-0-00086 (Projects R/CP-20 and R/CP-24) and No. NA85AA-0-SG095 (Project R/CM-31), and from the Oregon Division of State Lands. This research was conducted as a portion of the second author's master's thesis in Nuclear Engineering at Oregon State University.

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## Records available at Wyoming

The International Archive for Economic Geology (I.A.E.G.) at the American Heritage Center of the University of Wyoming offers a remarkable collection of documents for public use as a tool for scientific, historical, and commercial research. For Oregon, this collection contains 130 report files, 520 documents, 46 maps, and 135 related documents.

Through a gift from the ARCO Coal Company, the I.A.E.G. now has made the records of the Anaconda Company Geological Department (1895-1985) available to the public. The collection represents the largest body of private mineral and geological data available.

The Anaconda Collection contains 1.8 million documents and maps including prospect evaluations, mine examinations, operating records from Anaconda properties, and studies of broad regional or topical interest. It is accessible through a computer inventory, from which printouts of specific searches are available. The collection is made available and supports itself entirely through user fees.

The I.A.E.G. is a repository and research facility for original manuscripts from the field of economic geology. In addition to the Anaconda Collection, it holds files from more than 170 individual geologists and corporations. More information on the collections, services offered, and fees for use can be obtained from International Archive of Economic Geology, University of Wyoming, Box 3924, Laramie, WY 82071, phone (307) 766-3704.

—I.A.E.G. news release

## REMEMBER TO RENEW

If the code number on your address label ends in "1289," that means your subscription expires with the last issue of 1989. Please use the renewal form on the last page to make sure you will continue receiving *Oregon Geology*. And while you are at it—why not consider a gift subscription for a friend? □

## DOGAMI Governing Board appoints new chairperson

Sidney R. Johnson, president of Johnson Homes in Baker, has been appointed chair of the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI) for a one-year term, succeeding Donald A. Haagensen of Portland.

Johnson is currently serving both his second four-year term as a member of the Board and his second term as chairperson. He has been a board member since 1983 and served as chairperson in 1985-1986. Ronald K. Culbertson of Myrtle Creek also serves on the three-member Board. □

## BLM names new state director

D. Dean Bibles, currently U.S. Bureau of Land Management (BLM) state director for Arizona, has been named BLM state director for Oregon and Washington. He will succeed Charles W. (Bill) Luscher who retired September 1.

Bibles is a 32-year veteran of BLM and has held key management positions in the agency since 1967. He became state director in Arizona in 1982.

Bibles has received several awards, including the Interior Department's top recognition, the Distinguished Service Award, and the federal government's top award for senior service leaders, the Distinguished Executive nomination. In 1985 and 1988, he received awards in Arizona by the state's Parks and Conservation Association, Wildlife Foundation, and Nature Conservancy chapter.

In making the appointment, BLM Director Cy Jamison said that Bibles "is fully committed to management of our nation's public lands in that multiple-use context which will position BLM to fully meet the public's demands for natural-resource uses in the 1990's and into the 21st century.

—BLM news release

## Photographer Leonard Delano, Sr., dies

Leonard Delano, Sr., retired commercial photographer, died September 16, 1989, in a Milwaukie hospital. He and his wife Emily were active for more than 48 years in commercial photography, which included aerial-photography mapping work. Their companies, Delano Photographics, Inc., and Western Mapping Company, produced a significant collection of Pacific Northwest photographs, many of which have been given to the Oregon Historical Society.

John E. Allen, Emeritus Professor of Geology at Portland State University, said this of Delano, "Few professional photographers have contributed so much to geological understanding of the landscape as has Leonard Delano. This is because on every flight, Delano Photographics always made it a policy to also take a few spectacular oblique photographs. They were usually not paid for these, but when the shots were needed by a geologist for a superb illustration, Delano Photographics allowed them to be used for minimal or no charge."

Delano was one of the lucky few people who have the eye of an artist, the skill of a photographer, an interest in geology, and the opportunity to fly and photograph. Through his photographs, he shared his special vision with the rest of us. The Oregon Department of Geology and Mineral Industries used many of Delano's photographs—as did almost anyone else who has published information about the geology of the state.

Delano is survived by his wife Emily, sons Douglas and Leonard Jr., a brother, a sister, and seven grandchildren. □



# Industrial minerals: Can we live without them?

by Hal McVey, Mineral Marketing, Inc.\*

Few people realize the importance of industrial minerals in our everyday lives. Perhaps a trip through a normal working day will underscore our reliance upon these nonmetallic minerals. The products and processes that contain industrial minerals or utilize industrial minerals in the manufacturing process are highlighted in bold face.

As we step out of bed in the morning, we place our feet on the **carpet** (calcium carbonate/limestone is used in the carpet backing). We find our way to the kitchen and switch on the **electric light** and the **coffee pot**, which are made of either **glass** or **ceramics** (both glass and ceramics are made entirely from industrial minerals—silica sand, limestone, talc, lithium, borates, soda ash, and feldspar). As we enter the kitchen, we find we are now on **linoleum** (calcium carbonate, clay, and wollastonite) or on **ceramic tile**.

While the coffee is being prepared, we sit down to read the **newspaper** and at the same time we realize that we have to take a trip today, so we consult our **Official Airline Guide** and then have to refer to the **Yellow Pages** of the phone book for the phone number of the airline. (All of these papers are filled with kaolin clay and use limestone, sodium sulfate, lime, and soda ash in the processing.)

The coffee is prepared, and we fix a piece of **toast** and sneak a piece of **cake** from last night's party (bakery items such as bread contain gypsum as an ingredient, and cakes have a high content of gypsum in the icing). The **plate** from which we are eating is composed of **glass**, **ceramics**, or **china**, the last being a special form of ceramics. We might also feel inclined to have a full breakfast and even contemplate what we'll have for lunch and what has to be prepared for the evening meal. Regardless, all of the **food** that we eat every day relies completely on industrial minerals for its growth and production. (All **fertilizers** are composed of some combination of potash, phosphates, nitrogen, sulfur, and other minor minerals. The acidity of soils must be regulated with gypsum, limestone, or sulfur. In fact, without industrial minerals, there could not be any modern-day agriculture as we now know it.)

Let's now start getting to go to work. We brush our teeth with **toothpaste** (calcium carbonate/limestone/sodium carbonate). Women put on **lipstick** (calcium carbonate and talc) and **powder** (talcum), and men might prepare their hair with **hair cream** (calcium carbonate). Other forms of **makeup** would have various minerals as a constituent. The **lavatory counter top** in the bathroom where we are standing is a nice **synthetic marble** or **synthetic onyx** (titanium dioxide, calcium carbonate, and alumina hydrate). The **sinks**, **lavatories**, **toilets**, and similar fixtures throughout the house are kept shiny with **cleansers** (silica, pumice, diatomite, feldspars, and limestone). **Kitchen** and **bathroom tiles** are installed, are kept in place, and maintain their waterproof condition with **putty** and **caulking compounds** (limestone and gypsum).

Just before we leave, we want to brighten up our wardrobe with some form of **jewelry** (all precious and semiprecious stones—opal, amethyst, aquamarine, topaz, garnets, diamonds, etc., are industrial minerals). There is a less attractive task to do at the last

minute, changing the **kitty litter** (attapulgite, montmorillonite, zeolites, diatomite, pumice, or volcanic ash).

As we walk outside, we make a mental note that we have to have the **composite roof** fixed. (**Fiberglass** is composed of almost the same ingredients as regular glass—silica, borates, limestone, soda ash, and feldspar. Fiberglass and asphalt, along with lesser quantities of either talc, silica sand, or limestone, comprise composition roofing.) We are pleased to see that the fiberglass siding on our home that we have just installed looks so nice. As we get in the car, we think that we will have to do **planting** and **gardening** this evening. In addition to **fertilizers**, we will have to buy some **soil amendments** and **planting mixes** today. (Vermiculite, perlite, gypsum, zeolites, or peat make for better growth.)

Once we leave for work, we are really employing industrial minerals. Our **automobile** is literally composed of industrial minerals. Starting from the ground up, **tires** contain clays and calcium carbonate, and the **mag wheels** are made from dolomite and magnesium. All of the **glass** in the car is made entirely from minerals, as is the **fiberglass body** now becoming popular on many models. Many of the components in a car are now being made of **composites**, which are usually combinations of **fiberglass** and **plastics**. Plastics require calcium carbonate, wollastonite, mica, talc, clays, and silica for their manufacture. So, as we drive to work, we are enjoying the value of numerous industrial minerals, from the **bumpers** to the **dashboard** to the **radiator cap** and the **floor mats**.

The **paint** that makes our car so attractive is composed in large part from industrial minerals—titanium dioxide, kaolin clays, calcium carbonate, micas, talc, silica, wollastonite, and others. In fact, every speck of **all paints** that we will encounter today, from that on our house to the stripe down the middle of the road and the interior of our offices and elsewhere, will be composed mainly of industrial minerals.

Modern transportation is almost entirely reliant upon industrial minerals, and this does not stop with just the car. **Gasoline** and **lubricants** depend on industrial minerals, since the **drill bit** that originally discovered the crude oil was faced with industrial diamonds. **Drilling fluids**, used for ease of well drilling, are made almost entirely from barites, bentonite, attapulgite, mica, perlite, and others. It is necessary to employ clays and zeolites in the **catalytic cracking process** for crude petroleum to arrive at gasoline and lubricants.

On our way to work, we don't think about it, but we are literally riding on industrial minerals. **Concrete pavement** is composed of **cement** and **aggregates**. Aggregates are themselves industrial minerals—sand and gravel or crushed stone, such as limestone, dolomite, granite, lava, etc. **Cement** is manufactured from limestone, gypsum, iron oxide, clays, and possibly pozzolan. Even **asphaltic pavement** or **blacktop** has industrial minerals as aggregates.

The **building** we are about to enter is made of industrial minerals. If it is a **concrete** or **stone** or **brick** building, it is entirely made from industrial minerals. If there are **steel structural members**, the steel production process required chromite for fluxing, bentonite for pelletizing, and, perhaps, chromite for hardening. The making of **steel** requires the use of high-grade **refractory bricks** and **shapes** made from bauxite, chromium, zircon, silica, graphite, kyanite, andalusite, sillimanite, and clays. **Fiberglass batts** may be used for insulation in our office buildings as they are in our homes.

Upon entering, we are often enclosed by **wallboard** or **sheetrock** (gypsum with fire retardant additives, such as clays, perlite, ver-

\* This paper was first presented at a U.S. Geological Survey and California Division of Mines and Geology seminar on February 15 and 16, 1989. It is reprinted with permission from *Industrial Minerals*, in which it appeared in April 1989 (no. 259, p. 74 and 75). Further information on *Industrial Minerals* magazine can be obtained from the publisher's U.S. office at 220 Fifth Avenue, 10th Floor, New York, NY 10001, telephone 1-800-METAL 25 (in the U.S.) or 212-213-6202.

miculite, alumina hydrate, and borates) joined together with **joint cement** (gypsum, mica, clays, and calcium carbonates). Certainly the **plate-glass windows** are made entirely from industrial minerals. The **floors** or **decks** between floors will probably be made from concrete using **lightweight aggregate** (perlite, vermiculite, zeolites, or expanded shales).

To begin our work, we may pick up a **pencil** (graphite and clays) and make a list of things to do. One of the first items is to send out a few invoices that are backed with **self-contained carbon paper** (bentonite or other clays or zeolites). There are some articles to be ordered, so we pick up a **catalog** or **magazine** and unconsciously like the glossy feel of the **fine paper**, which is caused by a high content of kaolin clay or calcium carbonate along with titanium dioxide for extreme whiteness. Almost every **sheet of paper** that we use today will have used industrial minerals, such as talc, in its manufacturing process or will contain minerals as fillers and coaters. Even some **inks** will contain calcium carbonate or other fillers.

The morning has worn on, and it is time for a break. In addition to the coffee in the **coffee cup** (remember, it is made of industrial minerals), we decide to heat up a roll, and we place it in or on a **microwaveable container** (plastics filled and reinforced with talc, calcium carbonate, titanium dioxide, or clays).

While on break, we commence to ponder what we will do for the weekend and know that there are a lot of **recreational devices** we would love to employ. These include **golf clubs**, **tennis rackets**, **fishing rods**, and **skis**. All of these are now commonly made from graphite, or, a slightly "older" material, fiberglass. Even if we are planning a backpacking trip, our **pack frame** and **pots** and **pans** will be made of **aluminum** (all aluminum, for whatever usage, originates with bauxite, one of the most widely utilized industrial minerals).

**Communications equipment** employs numerous industrial minerals. The standard product of the industry for many years has been the **silicon chip**, which is made from quartz or silica, as the name implies. **Optical fibers** made from **glass** are replacing some copper wiring. The **television screen** or **computer monitor** is made of glass, but critical **tubes** contain phosphors made from the rare earths or lanthanides, a family of industrial minerals. Even the **superconducting materials** that are presently getting so much attention utilize industrial minerals (yttrium, lanthanides, titanium, zirconium, and barites) in their manufacture.

After a hard day at the office, we drop in for refreshments with our friends. A glass of **fruit juice**, **wine**, or **beer** would be refreshing, but all of these liquids use either perlite or diatomite as filter aids in their purifying and clarifying processes. If we should add **sugar** to any of our drinks, we are enjoying the benefits of industrial minerals, since limestone and lime are basic to the production of sweeteners. And, of course, our refreshments will be served in **ceramic mugs** or **glasses** composed entirely of our friends, the industrial minerals.

Filtering and purification are major duties of the industrial minerals. Our **drinking water** uses minerals for purifying and clarification (limestone, lime, and salt), as do the **waste water treatment plants** (zeolites, soda ash, lime, and salt). The **vegetable oils** we use are filtered by clays, perlite, or diatomite. And equally important to recreation is the utilization of all the minerals mentioned in this paragraph for the filtration and purification of water in swimming pools.

When we arrive home, we are not yet through with our exposure to our mineral friends. If we have to take **medicine** or **pharmaceuticals**, we may chew antacid pills essentially made of calcium carbonate. For **upset stomachs**, there are Milk of Magnesia (magnesia/dolomite) or Kaopectate (kaolin) and others made from clays such as attapulgite. And, who can forget the lovely **barium "cocktail"** (barites), which it is necessary to drink before getting X-rayed for gastrointestinal occurrences. Not to mention **tincture of iodine**

(iodine) for all those cuts and bruises. And, the lithium that is used to treat **mental disorders** started out as an industrial mineral.

Rounding out the picture are such diverse uses as abrasives for **sandblasting** ships or for making **sandpaper** for home or workshop use, as well as **emery boards** for our fingernails or **polishing compounds** for our silverware and other items. Abrasives are made from pumice, diatomite, silica, garnet, corundum, and emery. Or, **porcelain figurines** (silica, limestone, borates, and soda ash) for our what-not shelf and **plaster of paris** statues (gypsum) for our lawn.

Almost finally, it must be mentioned that one of the most basic **table ingredients** is an industrial mineral, namely salt. In fact, it is so basic that it was historically used as a medium of trade or payment, as implied in our word "salary." And truly finally, our names and dates of birth and death will be inscribed on a **gravestone** (marble or granite).

The foregoing is meant to provide a broad insight into the importance of industrial minerals in our everyday life and to emphasize how much our lives would be altered without ready and economical access to these fundamental constituents. □

## On recreational gold panning in Oregon

*This article is adapted from "The Lure of Gold," by Mel Ingeroi of the U.S. Bureau of Land Management (BLM), Roseburg District, and published in a recent issue of the newsletter BLM News, Oregon and Washington.*

"There's nothing quite like seeing your first gold flake shining against the sun. The yellow flakes sparkle like no other sight, and the sense of finding a bonanza leaves at least a few first-time miners giddy." With that glowing description begins an article on placer mining in the June 1989 issue of *Trailer Life*, a national magazine for recreational-vehicle enthusiasts. The article talks about the basic techniques (such as panning), equipment needed, and possible locations.

Because the primary location recommended is on Cow Creek in the BLM Roseburg District, BLM mining engineer John Kalvels has been busier than usually answering questions from the public. "We get all kinds," said Kalvels, "from the casual tourist who knows next to nothing about gold to the experienced dredger who asks only about mining claims. Some weeks we might get a dozen letters and another dozen walk-ins and telephone callers."

The discouraging fact is that most of the public land on Cow Creek is covered by mining claims. It is off limits, and miners have been known to be rather testy when running off claim jumpers. About the only spot on public land along Cow Creek still open to the public is in the vicinity of Darby Creek, about 20 mi southwest of Riddle. Currently, 20 acres have been withdrawn from mining entry there, and BLM is considering the establishment of a five-acre recreational gold-panning site within this area.

Kalvels has been a mining engineer for the Roseburg District for quite a while, and his knowledge of local geology, promising locations, and tall tales keeps his customers satisfied, even though he does not have much prime real estate to offer to gold panners. "There will always be people lured by the romance of gold mining," Kalvels says. "Part of it is the price paid for gold. At nearly \$400 an ounce, it ranks among the most valuable materials on earth. The rest is more intangible—tied in with mystery and challenge."

These intangibles are behind the recreational aspects of placer mining. Many of the first-time miners on Cow Creek do not leave with enough gold to pay for the gasoline it took to drive out there. But a fair number will come back, dedicated not to what they take home but to doing it and being there. □

# Industrial Minerals Forum meets in Portland

by Ronald P. Geitgey, Oregon Department of Geology and Mineral Industries

The Forum on the Geology of Industrial Minerals is a loosely knit non-organization of specialists involved in various aspects of industrial minerals exploration, analysis, marketing, and production. Each year a different state or provincial geological survey hosts the meeting and publishes the papers presented at the Forum.

During the first week in May of this year, the 25th Forum on the Geology of Industrial Minerals was held in Portland, Oregon, hosted by the Oregon Department of Geology and Mineral Industries and the Washington Division of Geology and Earth Resources. This is the first time the Forum has met in a West Coast state, and for many of the 120 participants from the United States, Canada, and Great Britain, it was their first visit to this area. About 45 persons were from the Pacific Northwest. The remainder were from the eastern and midwestern states. Thirty-five percent were government employees, and sixty-five percent were employed in

private industry. The Forum provided an opportunity for participants to learn about industrial minerals activities in the Pacific Northwest and to meet the industrial minerals specialists working in this region.

The Forum consisted of technical sessions, a local field trip, and a three-day field trip to eastern and central Oregon. Seventeen technical papers were presented, including surveys of industrial mineral production and occurrences in Idaho, Montana, Oregon, Washington, and British Columbia. Other papers described specific commodities, including bentonite, limestone, pozzolans, rare earths, talc, and zeolites, and two papers discussed various methods and problems in laboratory analysis of industrial minerals.

The Portland portion of the Forum concluded with a field trip to local industrial mineral producers, shippers, and users. Ross Island Sand and Gravel provided a tour by barge of its Willamette River operation, which supplies aggregate for the Portland metropolitan area. The Port of Portland hosted a tour of the Hall-Buck Marine, Inc., bulk mineral loading facility at Terminal 4 through which talc, bentonite, and soda ash are transferred from unit trains to ocean freighters for export. A tour of the Blitz Weinhard Brewery included a discussion of the brewery's diatomaceous earth filtration system and a stop in its hospitality room to test the efficacy of that system.

An optional field trip took 45 participants to industrial mineral operations in eastern and central Oregon. Stops included Ash Grove Cement West in Durkee, Teague Mineral Products in Adrian, Eagle-Picher Minerals in Vale and Juntura, Cascade Pumice Company in Bend, and stops and discussions at various points of historical and geologic interest.



Participants boarding barges for tour of Ross Island Sand and Gravel operation in the Willamette River in Portland, between the Sellwood and Ross Island Bridges.



Hall-Buck Marine, Inc., bulk mineral loading facility at the Port of Portland Terminal 4. Soda ash from Wyoming is being transferred from unit train to freighter.



The 216-ft, gas/coal-fired rotary kiln at Ash Grove Cement West in Durkee. Ground limestone and shale are fed in from the left, fused to clinker in the central 2,700 °F-hot zone, and the clinker is cooled and discharged at the right.

Ash Grove Cement West produces portland cement in a state-of-the-art plant, as well as high-purity limestone for sugar-beet refining. Its products are marketed in Northwest states, and for the last several years have been valued at about \$25 million per year.

Teague Mineral Products produces bentonite clay and the zeolite mineral clinoptilolite. Its bentonite is marketed for foundry binder and for engineering applications, including pond and lagoon sealants and impermeable membranes for solid-waste disposal sites. Teague



*Eagle-Picher Minerals diatomite mine near Juntura. Diatomite ore is trucked to the mill near Vale and processed into filter-aid products.*



*Cascade Pumice company loading facility near Bend. Crushed and sized pumice is shipped by truck or by rail.*



*Forum participants at Teague Mineral Products zeolite pit about 20 mi south of Adrian. The zeolite clinoptilolite is used in odor-control products and as a heavy-metal and radionuclide absorber.*

zeolite is used for odor control products and for heavy metal and radionuclide absorption.

Eagle-Picher Minerals mines diatomaceous earth or diatomite near Juntura and processes it at a plant near Vale. Carefully controlled processing results in diatomite products with specific size and shape characteristics valuable in the filtering of various juices, beverages, edible oils, and petroleum products.

Cascade Pumice Company produces pumice and cinder products in various size ranges. Most of the pumice is used as an aggregate to produce lightweight poured concrete and concrete blocks. Lesser amounts are used as absorbents, horticultural soil mixes, and to stone-wash blue jeans and other garments.

All of the producers on both field trips were very gracious hosts and major contributors to the success of the 25th Forum.

Proceedings of the 25th Forum on the Geology of Industrial Minerals and an index of 25 years of Forum proceedings will be published later this year by the Oregon Department of Geology and Mineral Industries. The 26th Forum will meet in Charlottesville, Virginia, in May 1990, and the 27th Forum will meet in Banff, Alberta, in May 1991. □



*Clinker from the rotary kiln at Ash Grove Cement West in Durkee. It is subsequently ground to a fine powder and blended with gypsum to make portland cement.*



# MINERAL EXPLORATION ACTIVITY

## Major metal-exploration activity

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services, Inc.	T. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	QM Chevron Resources Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
January 1989	Silver Peak Formosa Exploration, Inc.	T. 31 S. R. 6 W. Douglas County	Copper, zinc	App, com
May 1989	Hope Butte Chevron Resources Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl com

Explanations: App=application being processed. Expl=exploration permit issued. Com=interagency coordinating committee formed, baseline data collection started. Date=date application was received or permit issued.

## Exploration rule making

The Mined Land Reclamation Program (MLR) of the Oregon Department of Geology and Mineral Industries has organized a technical advisory committee to make recommendations for appropriate exploration drill-hole abandonment procedures required as a result of House Bill 2088. Based on those recommendations, the Department will propose rules and conduct public hearings for evaluation prior to adoption. Rule adoption is now anticipated for early 1990.

## Bond ceiling rule making

MLR has organized also a technical advisory committee to make recommendations for proposed rules required by Senate Bill 354.

The Senate bill authorizes the Department to set "the amount of the reclamation bond at an amount not to exceed the lower of the actual cost of reclamation or \$100,000 per acre of land to be mined under the terms of the operating permit, if the operating permit applies to extraction, processing, or beneficiation techniques the result of which

(a) will increase the concentration of naturally occurring hazardous or toxic metals . . . to a significantly higher level than that occurring naturally within the permit area; and

(b) is reasonably likely to present a threat to public safety or the environment."

Based on recommendations of the committee, the agency will propose rules and conduct public hearings for evaluation prior to adoption.

## Status changes

A project coordinating committee has been formed for the Hope Butte project of Chevron Resources Company.

In addition to its application to MLR for a mining permit, Formosa Exploration, Inc., has also applied to the Oregon Department of Environmental Quality (DEQ) for the required permit. DEQ will hold public hearings on its water-pollution control permit, if sufficient interest is expressed.

Readers who have questions or comments should contact Gary Lynch or Allen Throop at the MLR office in Albany, phone (503) 967-2039. □

## Eugene Mineral Club displays at Capitol

The display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem currently houses an exhibit provided by the Eugene Mineral Club. The materials displayed were contributed by 14 of the club's members and arranged by Dean and Betty Axtell, Marian Andrus, and Jean Long-fellow.

Ten Oregon counties are represented in the collection: Crook County with petrified wood, tube agate, and Carey agate; Harney County with thunder eggs and Paiute agate; Jackson County with jade; Jefferson County with thunder eggs, sunset agate, and petrified wood; Lake County with tumbled and faceted Oregon sunstones and obsidian; Lane County with carnelian and jasper; Lincoln County with jasper; Linn County with carnelian; Malheur County with Graveyard Point plume agate, petrified sagebrush, and pink, dendritic limb casts; and Wheeler County with Oligocene leaf and cone fossils in matrix.

One shelf of the display case shows samples of collected material in its raw form—unpolished. Another contains a beautiful display of Linn County carnelian.

The collection will be on display until January 15, 1990. It will be followed by an exhibit featuring Oregon's State Rock, the Thunderegg, and prepared by Bert Sanne of the Far West Lapidary Society of Coos Bay.

—OCRMC news release

## Electronic publishing begins

You may have noticed that this issue of *Oregon Geology* looks slightly different from earlier issues. That is because it is the first to be prepared electronically at the Department.

—Editors

## 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.*

**THE GEOLOGY OF THE EAST-CENTRAL DESOLATION BUTTE QUADRANGLE, GRANT COUNTY, OREGON**, by Neil Elfrink (M.S., Oregon State University, 1988 [compl. 1987]), 123 p.

Pre-Tertiary metamorphic rocks, Jurassic granitic intrusions, and Eocene basalts are exposed along the North Fork John Day River at its confluence with Granite Creek. Geochemical and textural evidence suggests greenschist-metamorphosed, strongly sheared, volcanogenic rocks originated in an island-arc environment. These greenstones were apparently intruded during the Late Permian by a silicic pluton that is similarly metamorphosed and brecciated. South of this arc terrane, tectonically disrupted ophiolitic rocks are exposed. This east-west-trending belt of melange contains blocks of chert, metagabbro, and metabasalt in a serpentinite matrix. Titanite indicates the original basalt may have been alkaline. Paleozoic or Triassic Elkhorn Ridge Argillite underlies much of the thesis area and consists mostly of contorted chert and argillite. Graywackes, greenstones, and limestones are intercalated with Elkhorn Ridge Argillite. Regional metamorphism is lower greenschist facies.

Two relatively fresh granitic stocks may be satellites of the Upper Jurassic Bald Mountain batholith exposed 9 km to the east. An intrusive sequence ranging from mafic quartz diorite to granite comprises the larger stock, exposed along Granite Creek. This pluton contains mostly quartz diorite and tonalite. A 0.5-km-wide stock of porphyritic tonalite intrudes argillite on the north side of the North Fork John Day River canyon. Mineral assemblages in the contact-metamorphic aureoles around the two stocks are characteristic of hornblende hornfels facies.

Tertiary dark-gray basalt overlies the Mesozoic and Paleozoic rocks at a profound unconformity. Geochemistry suggests the olivine-bearing, vesicular basalt is equivalent to the Clarno Formation exposed farther to the west.

**EXPLOSION STRUCTURES IN GRANDE RONDE BASALT OF THE COLUMBIA RIVER BASALT GROUP NEAR TROY, OREGON**, by Leonard L. Orzol (M.S., Portland State University, 1987), 220 p.

Explosion structures occur in flows of Grande Ronde Basalt in the study area near Troy, Oregon. Data from nineteen stratigraphic sites indicate that the maximum number of flows that contain explosion structures at any one site is six. In the informally named Troy flow, explosion structures are widespread.

Each flow that contains explosion structures can be divided into two cooling units. The first cooling units occupy troughs in the pre-eruption topography and are up to 10 m thick. The second cooling units contain the explosion structures and are up to 100 m thick. The thickness of flows that contain explosion structures ranges from 10 m to 150 m. A plot of the thickness of an explosion structure against the total thickness of the flow is linear with slope of approximately 0.5. The breccias within explosion structures average 42 percent of the total thickness of a flow.

The overall shape of an explosion structure is similar to a three-dimensional set of nested arches with a central spine of breccia that cuts through the uppermost arches. Jointing patterns follow the shape of the arches. The linear trends of the central spines within explosion structures of the Troy flow parallel either the northeast-trending Grande Ronde (N. 3° E.) fault system or the northwest-trending dike system in the area (N. 15° W.).

Two processes operate during the formation of explosion structures: mixing and fragmentation. These two processes produce unique intraflow zones within the second cooling unit. Petrographic textures of these intraflow zones range from vitrophyric to intersertal to intergranular. All three textures can be observed in thin bands or layers in samples from the upper intraflow zones of the second cooling units. Individual bands or layers are twisted, pinched, and swirled due to mixing. Fragmentation and mixing produce a vertically stratified central spine composed of three main types of clasts: vesicular to nonvesicular, scoriaceous, and pahoehoe types. Clast sizes range from lapilli size in the outer, matrix-supported margin to block size in the inner, clast-supported core.

Broad overall trends occur in geochemical data for the Troy flow and a flow stratigraphically above the Troy flow. Concentrations of particular elements increase or decrease in samples toward the base of the flow relative to the uppermost sample. K, La, Eu, and Ta are enriched and Fe and Co depleted greater than 10 percent toward the base of a flow in areas away from explosion structures. Particular elements are enriched (Ce, Hf) or depleted (Th) less than 10 percent toward the base. Where explosion structures are present within the flow, these broad overall trends are less pronounced, and few elements display these trends of enrichment or depletion.

**AN ANALYSIS OF THE EASTERN MARGIN OF THE PORTLAND BASIN USING GRAVITY SURVEYS**, by Steven A. Davis (M.S., Portland State University, 1988), 135 p.

The recent contributions of several investigators have indicated the Portland basin may be a pull-apart structure associated with wrench tectonism. Because of the large density contrast between sedimentary and volcanic units and because of their reasonably uniform and continuous nature, gravity survey methods can be used to identify covered structures with considerable success. The study utilized gravity modeling techniques to investigate the structure and genesis of the Portland basin's eastern margin.

Two gravity surveys were completed across pronounced lineaments which form an apparent eastern boundary for the basin. In all, 175 stations were measured, bimodally distributed in regional control and detailed area section in the 9.47-km Fourth Plains and 11.43-km Interstate gravity lines. These values were reduced by standard methods to yield a free-air gravity anomaly value used in the computer modeling process. The Bouguer gravity was not used, since strata normally removed by the Bouguer correction were required for proper interpretation.

Both gravity lines revealed the existence of negative anomalies ranging in magnitude from 1 to 6 mgals, being areally consistent with the locations where the lines crossed lineaments.

Computer modeling indicated these anomalies were produced by strongly prismatic bodies occurring in the near-surface section. Some were small enough to be nearly undetectable under the given survey resolution, while others attained cross sections measuring nearly 3 km<sup>2</sup>.

Folding, faulting, and erosion were investigated as reasonable generative processes for these bodies. Based on the synthesis of modeling and the known geologic history of the region, faulting is preferred. The study defines the Lackamas Creek and Sandy River faults. Each can be characterized as an extensive linear zone of locally normal and/or grabenlike failure where normal displacements approach 300 m. These structures combine to form a region nearly 50 km in length, trending N. 40° - 45° W., effectively paralleling the Portland Hills complex which bounds the basin to the west.

A dextral stepover, characteristic of dextral strike-slip failures, and a resulting concentration of extensional deformation is delineated in the region of the Interstate line. Dextral movement is suggested by this incipient pull-apart, the stepover itself, and the overall geometry of the faults.

**GEOLOGY AND REVISED STRATIGRAPHIC INTERPRETATION OF THE MIOCENE SUCKER CREEK FORMATION, MALHEUR COUNTY, OREGON**, by David C. Lawrence (M.S., Boise State University, 1988), 54 p.

Miocene volcanic and sedimentary rocks originally mapped as Sucker Creek Formation near Adrian, Oregon, and Succor Creek State Park include a stratigraphic section of at least 1,539 m of westward-tilted and faulted deposits. Mapping indicates a stratigraphic section that can be divided into four mappable units in T. 23 S., R. 45 E.; T. 23 S., R. 46 E.; and T. 24 S., R. 46 E.

The main sedimentary section overlies basalts and silicic volcanic rocks at least 200 m thick, exposed along Succor Creek. Starting with the basal unit, the section consists of 198 m of bentonitic claystones containing a white volcanic ash and a prominent orange sandy siltstone; 31 m of alternating thinly bedded diatomite (partly altered to porcellanite) and bentonitic claystones; 279 m of olive-gray bentonitic claystones with several layers of white volcanic ash and, in the upper part, interbedded with 38 m or more of conglomerates and gravels. Above this dominantly claystone basal unit is a 594-m sequence of palagonite tuffs containing minor basalt flows, dikes and sills, overlain by a rhyolite dome complex that is locally 107 m thick, then a 19-m thick zone of thinly-bedded pumice lapilli and ash. The uppermost unit in the section is a 92-m-thick pale-greenish rhyolite tuff. The basalt and palagonite unit is apparently localized near and north of Devils Gate, but the underlying lacustrine claystone section is more widespread in the region.

The section is broken and partially repeated in several normal fault blocks. Because the stratigraphic section includes considerable amounts of claystone, this section contrasts markedly with the type section, described by Kittleman and others (1965) about 9 km south of this study area. That type section is 178 m of mostly volcanoclastic sandstone.

The differences in stratigraphic sections indicate that, in this report and the section described by Kittleman and others, beds and no one type section can be considered typical. Similar rocks occur at depths of 2,865-3,828 m beneath the Snake River Plain near Meridian, Idaho, in the J.N. James well, in a section containing about 950 m of claystone.

Preliminary synthesis of detailed sections of the formation mostly indicates that the Sucker Creek Formation indicates bimodal volcanic rocks, and sedimentary-facies rocks. Volcanic ash layers in the lacustrine claystones are the best marker beds for regional correlation, and their recognition may provide a basis for understanding the basin evolution.

**GEOLOGY, GEOCHEMISTRY, AND MINERALIZATION OF THE YELLOWBOTTOM-BOULDER CREEK AREA, LINN COUNTY, OREGON**, by David K. Nicholson (M.S., Oregon State University, 1989 [completed 1988]), 186 p.

The Yellowbottom-Boulder Creek area is immediately west of the Quartzville mining district in the Western Cascades of Oregon. Volcanic rocks comprise a series of basaltic to rhyodacitic flows and volcanoclastic deposits that are believed to correlate with the Sardine Formation (mid-Miocene). These volcanic rocks dip to the southeast (5° to 25°), presumably into the hinge zone of the Sardine syncline located immediately to the east.

Intrusive rocks consist of small stocks of intermediate composition (quartz diorite, quartz monzodiorite, quartz monzonite, granodiorite, and tonalite), and dikes and plugs of basaltic to rhyolitic composition. The largest intrusion is a quartz monzodiorite stock that covers approximately 1 km<sup>2</sup>, for which the name Yellowbottom Stock is proposed here.

Pliocene flows of diktytaxitic basalt and porphyritic andesite of High Cascade origin are preserved on the crests of Galena Ridge and Packers Divide. A Quaternary flow of trachybasalt partly

fills the valley of Canal Creek and is associated with two cinder cones: They presumably represent the last pulse of volcanic activity in the Quartzville area.

Major-oxide concentrations in the volcanic and plutonic rocks display systematic trends (decreasing Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, FeO<sub>T</sub>, MgO, CaO, and P<sub>2</sub>O<sub>5</sub>, and increasing BaO and K<sub>2</sub>O, with increasing SiO<sub>2</sub> content) on Harker variation diagrams. These trends may suggest differentiation from a single batch of magma. The chemistry of plutonic rocks from the study areas, and from the Western Cascades in general (calc-alkaline, low K<sub>2</sub>O content), is similar to that of some island-arc terranes, including the Southern California batholith, Caribbean, southwestern Pacific, and Pacific Northwest areas, and largely suggests that the magma was derived from the mantle with little if any crustal contamination.

Hydrothermal alteration has affected all rocks of Miocene age. Propylitic alteration is widespread in areal extent and is thought to have been produced by the interaction of magmatic fluids with the host rocks. In contrast, argillic-phyllitic alteration is structurally controlled, and may have resulted from hydrolysis reactions between the hosts and meteoric waters that invaded the structures subsequent to propylitization. Zones of brecciated and silicified rock range from linear to cylindrical in shape and are commonly mineralized.

Comparisons of the concentrations of trace metals (Ag, Cu, Pb, Zn, and Mo) with those in average granodiorite, Caribbean intrusions associated with porphyry-copper deposits, and rocks of the Western Cascades indicate that samples of the Yellowbottom-Boulder Creek area are depleted in Cu, Pb, and Zn and enriched in Ag. Strong correlations are observed (Mo-Ag; Cu-Zn), whereas Pb has an antipathetic relationship to both Cu and Zn. Trends derived from data plotted on a Cu-Pb-Zn ternary diagram suggest that Pb and Zn metallizations are associated with vein-type deposition, whereas a one-sample Cu anomaly may be related to porphyry-type mineralization. Mineralized districts to the north in the Western Cascades are more enriched in copper than the Yellowbottom-Boulder Creek area, whereas those to the south contain more zinc. This change in the abundances of trace metals may be related to the depth of erosion that has exposed deeper levels of the hydrothermal systems in districts to the north.

Sulfur-isotope data suggest a magmatic source of sulfur. Depositional temperatures (157° to 260 °C) obtained from sulfur-isotope fractionation and fluid-inclusion data derived from a quartz-calcite-galena-sphalerite veinlet suggest mineralization during late-stage gradual cooling of the hydrothermal system.

Several geologic features, including mineralized breccia pipes and zones, quartz-bearing porphyritic intrusions, and anomalous metal concentrations, suggest the presence of a porphyry-type hydrothermal system at depth in the Boulder Creek area. Additionally, linear zones of intense silicification may be associated with shallower mineral deposition in the epithermal environment. The future mineral resource potential of the area is therefore largely, but not completely, dependent on the discovery of porphyry-type mineralization that might be enhanced by association with anomalously high gold and silver concentrations. □

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*Beverly F. Vogt*, Publications Manager

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