

# OREGON GEOLOGY

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JULY/AUGUST 1988



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Basalt hydrovolcanic deposits near Owyhee Reservoir  
Well logging of oil and gas wells in Oregon  
Blowhole near Black Butte Ranch

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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

View to the southeast across Dry Creek (see article beginning on next page). The stratigraphy in foreground, in ascending order: Second tephra deposit, lacustrine to fluvial sediments, sequence of 12 basalt flows, fluvial sediments, and local caps of intracanyon basalt. Knob in intermediate distance at left side of photograph and ridge in center of photograph are Dry Creek Buttes. Location of vent area for third tephra deposit, a maar, is the low hill immediately to right of Dry Creek Buttes. Photograph by Leonard Farr, Department of Geology, Portland State University.

# OIL AND GAS NEWS

## Northwest Petroleum Association symposium

The annual symposium and field trips of the Northwest Petroleum Association were held May 18-20, 1988, in western Washington. Meetings were held at Ocean Shores, Washington. Two field trips were conducted this year, one in the Chehalis Basin between Chehalis and Ocean Shores to look at Tertiary marine sands, and one along the Olympic Peninsula coast to see late Tertiary units, structural relationships, and hydrocarbon seeps.

The one-day symposium featured nine speakers plus a dinner talk on Mount St. Helens. Papers covered such topics as the Astoria and Grays Harbor Basins, volcanic stratigraphy, mineral exploration on Weyerhaeuser lands, Olympic Peninsula accretionary terrane, and the Oregon-Washington Outer Continental Shelf planning area. The symposium was attended by about 55 persons.

## Minerals Management Service conference

The Minerals Management Service (MMS) held its Conference-Workshop on Recommendations for Studies in Washington and Oregon Relative to Offshore Oil and Gas Development on May 23-25, 1988, in Portland, Oregon. A similar conference was held in 1976, but the latest meeting served as a much-needed update for the MMS to develop an understanding of research needs and priorities for the Washington and Oregon planning area. Lease Sale No. 132 for the Outer Continental Shelf off the two states is scheduled for 1992, and the Environmental Studies Program for the area is already underway.

Twenty speakers gave reviews of the state of the art in various scientific disciplines on the first day of the conference. The second day was spent with nine different discipline-oriented subgroups to develop recommendations to the MMS for additional studies in preparation for the lease sale and for tracking the effects of the sale.

Industry interest in Lease Sale No. 132 is still unknown. The Request for Interest, required for Frontier Areas, will be issued in November 1989 and is the next milestone in the process. This step will help to determine whether there is sufficient industry interest to continue to the Call for Information.

## Drilling begins at Mist Gas Field

Oregon Natural Gas Development has begun drilling at the natural-gas storage project at the Mist Gas Field in Columbia County. Well IW 33D-3, located in SE 1/4 sec. 3, T. 6 N., R. 5 W., was spudded on May 19 and has a proposed total depth of 2,900 ft.

This is the second injection-withdrawal well in the depleted Flora Pool which is now being used for gas-storage purposes. An injection-

(Continued on page 94, *Oil and gas*)

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# Basalt hydrovolcanic deposits in the Dry Creek arm area of the Owyhee Reservoir, Malheur County, Oregon: Stratigraphic relations

by Michael L. Cummings and Lawrence P. Growney\*, Department of Geology, Portland State University, Portland, Oregon 97207

## ABSTRACT

Basalt hydrovolcanic deposits occur at three stratigraphic levels and are interbedded with fluvial and lacustrine felsic volcanoclastic sediments south of the Dry Creek arm of the Owyhee Reservoir. The earlier formed hydrovolcanic deposits were partially to totally buried by felsic detritus before subsequent basalt hydrovolcanic eruptions.

The three lithologic associations found within the hydrovolcanic deposits are (1) explosion breccias containing blocks of basalt and sediments of underlying units within a matrix of lithic fragments and palagonitized basalt glass; (2) interbedded, poorly bedded to massive deposits composed of juvenile basalt glass and lithic fragments; and (3) moderately to well-bedded, planar to cross-bedded vitric and lithic lapilli tuffs.

A diatreme is exposed beneath the uppermost deposit of basalt tephra, and the walls of the diatreme widen upward toward the paleosurface. Basalt scoria breccias with a matrix of altered basaltic glass and blocks of country rock occupy the diatreme and are cut by irregularly shaped intrusions and dikes. Calcite and zeolites are cements in all hydrovolcanic deposits. Calcite veins to 0.5 m wide are common in the lower two tephra sequences.

The first hydrovolcanic deposit is interpreted as a tuff cone; the second has features characteristic of a tuff cone near its base but grades upward to features that are more similar to those of a tuff ring; the third is a tuff ring that has characteristics of a maar and contains interbedded basalt flows and palagonite within the crater.

## INTRODUCTION

Tuff rings, tuff cones, and maars are formed by hydrovolcanic eruptions produced by the interaction of rising magma with surface and/or ground water. The resulting hydrovolcanic deposits are varied depending upon the availability of water and the depth at which the magma intersects water (Fisher and Waters, 1970; Wohletz and Sheridan, 1983; Lorenz, 1985). The characteristics and formation mechanisms of these deposits are presented by Fisher and Waters (1970), Lorenz (1973), and Wohletz and Sheridan (1983) and reviewed by Lorenz (1985). In the Pacific Northwest, maars, tuff cones, tuff rings, and cinder cones of Pleistocene and younger age are present in the High Lava Plains of central Oregon (Lorenz, 1970; Heiken, 1971) and in the Snake River Plain in Idaho (Womer and others, 1980, 1982).

These topographic features and those from such sites as the Rio Grande Rift in New Mexico (Seager, 1987) and the classic localities in the Eifel region of Germany (Lorenz, 1973) are relatively young features that are partially eroded and that occur as craters and associated ejecta deposits. However, hydrovolcanic deposits south of the Dry Creek arm of the Owyhee Reservoir in Malheur County are interbedded with felsic volcanoclastic sediments of the Miocene Deer Butte Formation (Kittleman, 1962; Kittleman and others, 1965). Earlier formed hydrovolcanic deposits were partially to totally buried by felsic volcanoclastic sediments before subsequent hydrovolcanic eruptions. These deposits and enclosing volcanoclastic sediments are

presently exposed in valleys and canyons that are tributary to Dry Creek and the Owyhee River. In this paper, we describe the sedimentary and volcanic features and stratigraphy of the hydrovolcanic deposits located south of Dry Creek arm and the implications of these deposits for the volcanic and sedimentary history of the Owyhee area.

## SEDIMENTARY AND VOLCANIC FEATURES OF HYDROVOLCANIC DEPOSITS

### Stratigraphy and lithology

Three stratigraphically distinct basalt tephra deposits have been identified south of the Dry Creek arm of the Owyhee Reservoir (Figure 1). The deposits are interbedded with felsic volcanoclastic sediments. Thickness variations in the tephra deposits within the map area suggest that deposits from numerous eruptive centers coalesce within each stratigraphic level. However, since our mapping has been on a reconnaissance basis, we are not certain of the number of centers that contributed to each stratigraphic level.

The general stratigraphic sequence and geologic map of the area are illustrated in Figure 1. The base of the first basalt tephra deposit is not exposed in the study area. It is overlain by lacustrine felsic volcanoclastic sediments that grade upward into fluvial sediments. Trees rooted in the fluvial sediments occur as casts and molds in the base of the second hydrovolcanic deposit. In the western part of the study area, the second sequence of tephra deposits directly overlies those of the first. Lignitic paludal sediments immediately overlie the second basalt tephra and grade upward into fluvial backswamp facies. A sequence of at least 12 basalt flows lacking sedimentary interbeds overlies these sediments. The lowermost flows form a thick pillow-palagonite complex in the area of Dry Creek. South of Dry Creek, the lower flows are significantly thicker than the upper flows in the sequence. Fluvial, fine-grained sands and siltstones that contain fish scales and leaf fossils were deposited over the basalt flows before the third hydrovolcanic eruption. The third basalt tephra deposit is overlain by, and thins and grades laterally into, the felsic fluvial sediments.

A diatreme is exposed in the third eruptive center. In the area of the diatreme, the underlying stratigraphy is disturbed by faults and medium-grained basalt intrusions. Upward, the walls of some of the intrusions flare outward, and these intrusions grade into dense and scoriaceous basalt clasts in a palagonitized matrix. The upward flaring of the diatreme cuts out stratigraphic units, including the basalt-flow sequence and the overlying and underlying felsic volcanoclastic sediments, to form a crater. The morphology of the crater is characteristic of maar volcanoes. Fine-grained basalt dikes at various orientations occur within the faulted area that contains the irregularly shaped intrusions. At least two north-trending dikes are present in what is believed to be the center of the diatreme. These dikes and surrounding country rocks are silicified and contain disseminated pyrite. The dikes may have been feeders for the basalt flows that occupy the crater of the maar. Approximately 100 vertical m of the diatreme are exposed along the walls of tributary canyons to the main north-trending canyon in the study area.

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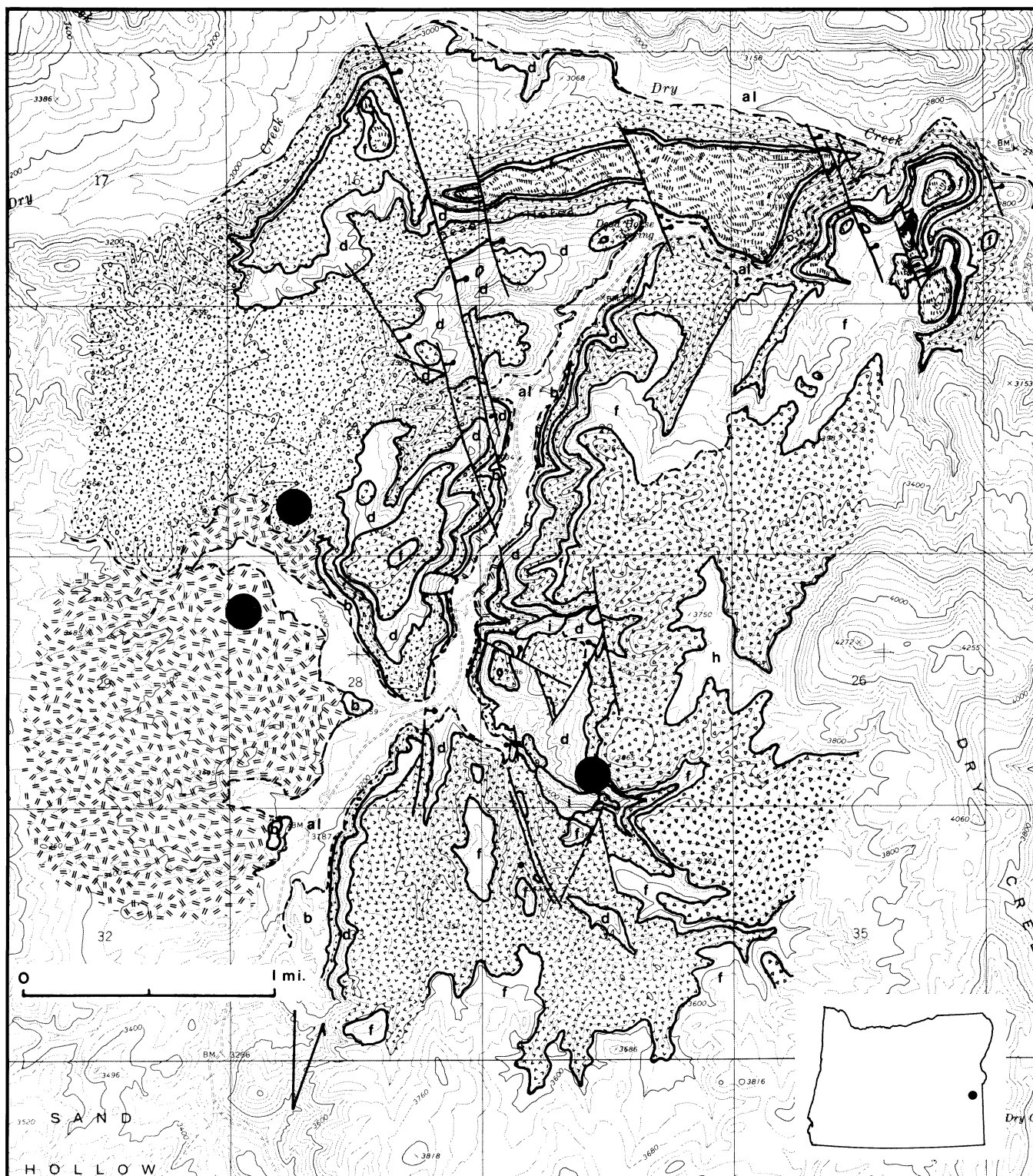
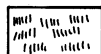


Figure 1. Geologic map of the area south of the Dry Creek arm of the Owyhee Reservoir, Malheur County, Oregon. The large black circles represent approximate locations of inferred/observed vent areas. Explanation of stratigraphic units on facing page.

## EXPLANATION

al

**Alluvium**--Unconsolidated alluvial deposits along stream channels



**Intracanyon basalt flows**--Columnar-jointed (lower) to chaotic internal morphology, locally invasive into sediments (upper)

h

**Felsic fluvial volcanoclastic sediments**--Interlayered and underlying intracanyon basalt flows. Composed of medium- to fine-grained sandstones and siltstones



**Third basalt tephra deposit**--Morphology of crater indicates a maar surrounded by a tuff ring. Basalt flows interlayered with palagonite occur in crater area. Irregularly shaped intrusions, breccias, and dikes cut the stratigraphy in diatreme exposed in canyons cut into crater area

i

Basalt to gabbro intrusions within the diatreme of the maar

f

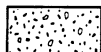
**Felsic fluvial volcanoclastic sediments**--Tree-leaf fossils in overbank deposits, fish scales in cross-laminated, medium- to fine-grained sandstones



**Basalt flow sequence**--Up to 12 basalt flows that range from 20 to 3 m thick. Lower flows are pillowed at the base in the Dead Horse Creek Canyon area and form a thick pillow-palagonite complex along the north wall of Dry Creek Canyon. Sequence thins onto flank of second basalt tephra deposit

d

**Felsic fluvial volcanoclastic sediments**--Thin lignite seams in lower, backswamp-dominated facies. Channel facies are more common in upper part of unit



**Second basalt tephra deposit**--Well-exposed deposits of poorly bedded lahar and surge deposits to well-bedded vitric, lithic lapilli tuffs. Crystalline rhyolite lapilli fragments are common, especially in upper part of tephra deposit

b

**Lacustrine sediments grading upward to fluvial felsic volcanic sediments**--Pelecypods common in lacustrine deposits; gastropods and pelecypods near top of lacustrine deposits; gastropods in fluvial deposits. Basalt detritus common near contact with first basalt tephra deposit



**First basalt tephra deposit**--Interbedded, poorly bedded to massive deposits of juvenile basalt glass; lithic fragments are abundant. Lahars and block and ash flows common

In the case of the second hydrovolcanic deposit, all exposed materials were deposited upon the contemporary surface. The relation between the deposits of the first eruptive center and the contemporary surface is not known, because the base of the deposit is not exposed in the study area.

Within the three basalt tephra deposits, we have differentiated three lithologic associations on the basis of bedding features, clast sizes, and overall geometry. These are (1) explosion breccia containing blocks of basalt and sediments from underlying units within a matrix of lithic fragments and palagonitized basalt glass; (2) interbedded, poorly bedded to massive deposits composed of juvenile basalt glass and lithic fragments; and (3) moderately to well-bedded, planar to cross-bedded vitric and lithic lapilli tuffs. The three lithologic associations are systematically distributed relative to both the location of the vent and stratigraphic level within the deposits. The approximate thicknesses and general characteristics of these associations for each of the three tephra deposits are presented in Table 1.

The explosion breccia (first lithologic association) is exposed only in the maar. These chaotic deposits contain blocks from underlying stratigraphic units within a matrix of rock fragments and palagonite. Field relations suggest that the materials were deposited at the approximate level of the paleosurface adjacent to the eruptive vent. A wide range of sizes and compositions of clasts includes blocks of dense and scoriaceous basalt from the underlying basalt flow sequence and volcanoclastic sediments. Blocks of basalt and amygdaloidal basalt are up to 1 m in diameter and display distinct reaction rims that are up to 5 cm wide (Figure 2). The deposits are at least 25 m thick in the maar. They are pervasively altered, and calcite and zeolite veining is common.

The second lithologic association, interbedded, poorly to massive bedded deposits composed predominantly of juvenile basalt glass, includes three types of deposits (A, B, and C). The A type contains block and ash-flow breccias overlain by glass-rich materials with large-scale cross-bedding (Figure 3). These deposits locally occupy channels within underlying deposits. Clasts within the block and ash-flow breccias include basalt; scoriaceous basalt, and, especially in the second tephra deposit, clasts of purple-gray, flow-banded rhyolite. These rhyolite clasts are rounded and seldom larger than 8 cm in diameter.

The B type consists of unsorted to poorly sorted deposits that locally occupy channels within older deposits. These deposits are similar to the block and ash-flow breccia deposits of the A type but lack the upper cross-bedded deposits. The bedding and sorting characteristics and geometry of the deposits indicate that the A type was formed as base-surge deposits, whereas the B type was formed as lahars.

The A and B types are interstratified with the C type: poorly to moderately well-bedded, porous deposits of irregularly shaped clasts of glass, scoria, and dense basalt (Figure 4). Ballistic stones of scoriaceous and dense basalt form bedding sags within the bedded deposits.

These three types of deposits (A, B, and C), which occur proximal to inferred vents and are particularly common in the first and second hydrovolcanic deposits, are less abundant proximal to the vent of the maar.

The third lithologic association, the moderately to well-bedded, planar to cross-bedded, vitric to lithic lapilli tuffs, occurs stratigraphically high in the tephra deposits and extends to the greatest distance from the vents. The moderately well-bedded deposits contain beds up to 15 cm thick of glassy, coarse lithic and vitric lapilli interbedded with finer grained, more prominently bedded vitric lapilli. In coarser grained beds, primary porosity was high, and the various basalt fragments form the framework of the bed. Bedding planes are at low angles and are seldom clearly distinguished. The diffuse bedding planes are locally wavy, but internal sedimentary textures within the beds have not been observed. Ballistic stones up to 12 cm in





Figure 2. Rounded to angular blocks of massive and scoriaceous basalt and cobbles of felsic volcanoclastic sediments in a matrix of basalt glass and rock fragments. Reaction rims around blocks are up to 5 cm wide. Calcite and zeolite veining cuts the matrix. Photograph is of the explosion breccia (first lithologic association) near the vent of the third tephra deposit. Photograph by Leonard Farr, Department of Geology, Portland State University.

diameter form asymmetric bedding sags within these deposits. The stones are usually dense basalt as illustrated in Figure 5.

Where the deposits of the third lithologic association are moderately to well bedded, bedding planes are planar and range from low-angle cross to parallel. Beds are up to 5 cm thick, and bedding planes are distinct. The clasts within a bed are of approximately similar grain size but are of a different size in the sub- and superjacent beds. Grain sizes range from ash to lapilli up to 1 cm in diameter. Clasts consist of palagonitized basalt glass and sparse scoria. Accretionary lapilli up to 1 cm in diameter occur in beds containing scoriaceous basalt glass, ash-size fragments of basalt glass, and agglutinated basalt glass. Figure 6 illustrates the fine-scale concentric layering in the lapilli. Within the second tephra deposit, rhyolite clasts are common to abundant, especially stratigraphically high in the deposit. These rhyolite clasts are illustrated in Figure 7.

Figure 8 illustrates low-angle laminated vitric-lithic tuff that occurs near the stratigraphic top on the flank of the second tephra deposit. Similar deposits are also locally present in the first tephra deposit. However, those within the second deposit contain abundant angular to rounded rhyolite lithic fragments within bedded palagonite. Although rhyolite lithic fragments occur throughout the stratigraphy of the second deposit, they are particularly common in these materials.

The color of the tephra deposits changes from the brown color that is common near the vent to a pale olive green in the distal deposits. Bedding planes in these distal deposits are parallel, and beds are commonly less than 0.5 cm thick. The grain size is commonly distinctly different between adjoining beds but uniform within the bed. Clasts range in size from ash to fine lapilli. The lateral distance traversed from the vent to the most distal deposits is approximately 2.5 km, as measured in the uppermost hydrovolcanic deposit. The tephra deposits grade into, and are interdigitated with, laterally contemporaneous felsic volcanoclastic sediments. Fine-grained basaltic detritus composed of glass and rock fragments occurs within the felsic sediments.

Although the distal deposits grade laterally outward into felsic volcanoclastic sediments, the overall stratigraphic relation between the felsic detritus and tephra deposits is transgressive. These sedimentary deposits partially to totally buried the tephra before the next hydrovolcanic eruption.

In addition to the three lithologic associations observed in the three tephra deposits, basalt flows are present in the vent area of the maar. These basalt flows are from 1.5 to 2 m thick and are interbedded with palagonite units of similar thicknesses. The interbedded sequence of flows and palagonite is bounded by massive, unsorted deposits, and flows may be locally invasive into such deposits. The basalt flows are aphanitic and contain xenoliths of medium-grained, holocrystalline basalt, as illustrated in Figure 9. As indicated, the basalt flows occur within the crater of the maar; however, isolated pods and lenses of basalt occur within a breccia in the northern flank of the maar. These pods and lenses are rootless and display radial cooling fractures. The matrix lacks clearly defined bedding. It is believed that the matrix consists of disturbed, originally bedded deposits of the third lithologic association.

### Alteration and cementation

The tephra deposits are pervasively altered. All primary basalt glass has been converted to clay minerals, and the porosity is partially to totally infilled with calcite and zeolites. Where calcite is particularly abundant, the tephra deposits form steep cliffs and pillars. Calcite veins form anastomosing networks that are oriented along north to north-northwest trends. Zones containing numerous veins are up to 1 m wide, and individual veins contained therein are up to 20 cm wide.

Color anomalies that are red in contrast to the overall brown to olive-green color of the tephra deposits occur near or within the vent areas. Examination of rocks from within the color anomalies suggests that oxidation of the basalt glass and leaching of the glass generated secondary porosity. A green secondary mineral, believed to be celadonite, is deposited within the secondary pores. The distribution of leached areas and precipitated celadonite is irregular but may be more prominent along north-trending fractures.

Within the diatreme of the maar, the basalt dikes and surrounding sediments contain disseminated pyrite where silicified. These silicified zones have been observed only within the diatreme.

### DISCUSSION

The tephra deposits in the stratigraphic section south of Dry Creek are well exposed in the canyons of the area. In addition, the interfingering field relations between basalt tephra and felsic volcanoclastic sediments provide an opportunity to examine evidences of the dynamics of the depositional system in which the tephra was



Figure 3. Block and ash-flow breccia overlain by vitric lapilli tuff with sparse lithic fragments and large-scale cross-bedding. Left of center of the photograph, moderately to poorly bedded basalt vitric tuff occupies a channel within the cross-bedded sequence. This photograph illustrates the A type of the second lithologic association within deposits of the first tephra deposit.

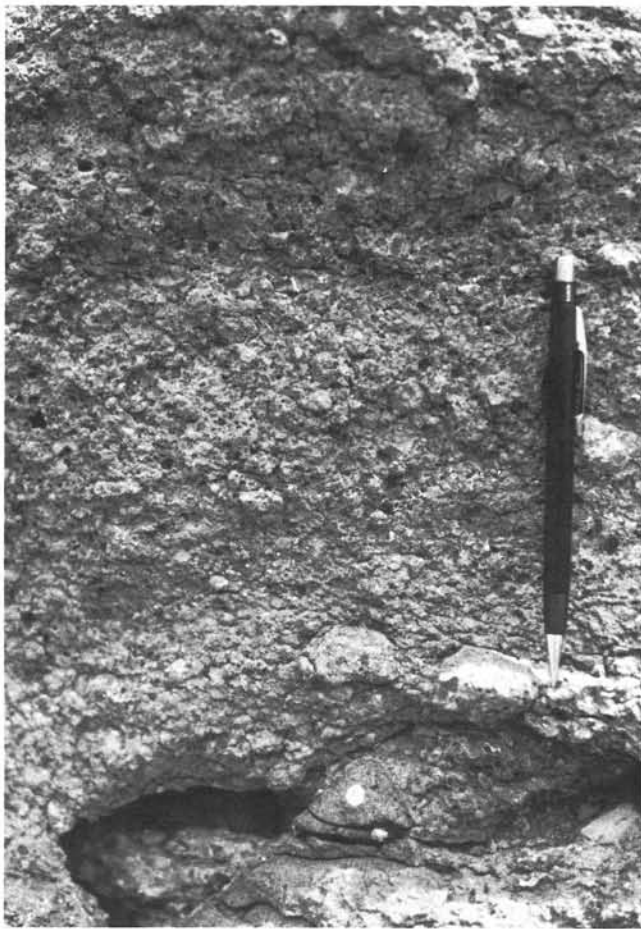


Figure 4. Porous lapilli tuff composed of basalt glass and sparse basalt scoria and basalt clasts. Beds of similar deposits occur within the second and, to a lesser extent, the third lithologic associations. The mechanical pencil is 12.5 cm long.

formed. The tephra deposits were produced by interactions of the hydrologic and magmatic systems in the basin in which the Miocene Deer Butte Formation accumulated. These interactions will be examined in relation to (1) the character of the eruptions that produced the tephra, (2) the paleohydrologic conditions of the basin, and (3) the spatial and stratigraphic distribution of similar basalt tephra deposits in the Owyhee region.

The vertical and horizontal distribution of the three lithologic associations described above varies among the three tephra deposits. The first tephra deposit contains mainly deposits of the second lithologic association: interbedded, poorly bedded to massive deposits composed of juvenile basalt glass and lithic fragments. The second tephra deposit contains deposits of the second lithologic association near the inferred vent area but is characterized by deposits of the third lithologic association (moderately to well-bedded planar to cross-bedded vitric and lithic lapilli tuffs) throughout most of its stratigraphy. The third tephra deposit, the maar, contains deposits of the first lithologic association near the vent (explosion breccia containing blocks of basalt and sediments from underlying units within a matrix of lithic fragments and palagonitized basalt glass) overlain primarily by deposits of the third lithologic association. This maar also contains lava flows interlayered with palagonite within the crater. Field relations suggest that these flows overtopped the north rim of the crater and became mixed into the deposits of the third lithologic association on the north flank of the maar.



Figure 5. A bedding sag within moderately to well-bedded lapilli tuff of the third lithologic association as it occurs within the second tephra deposit. The mechanical pencil is 12.5 cm long.

Wohletz and Sheridan (1983) related the bedding and geomorphic characteristics formed by hydrovolcanic eruptions to the character of the eruption phenomena. Thickly bedded deposits containing abundant ballistic fall, massive surge bed forms, and lahar deposits are characteristic of tuff cones. Tuff cones tend to form under conditions where eruption clouds are poorly inflated and deposits are wet, cohesive, and massive. Such deposits are similar to those of the second lithologic association in the Dry Creek tephra deposits. Thinly bedded deposits that have traveled farther from the vent are deposited from highly inflated eruption clouds characteristic of tuff rings (Wohletz and Sheridan, 1983). The deposits are drier and less cohesive than the deposits of tuff cones. These deposit characteristics are similar to those of the third lithologic association identified in the Dry Creek tephra deposits. The initial deposits of tuff rings are reported to be explosion breccias formed near the vent. Such explosion breccias are similar to the first lithologic association in the Dry Creek deposits.

On the basis of the sedimentary characteristics of the deposits, the first tephra deposit is interpreted to be a tuff cone. The second tephra deposit has characteristics of a tuff cone during its early eruptive history but contains deposits more similar to a tuff ring higher in its stratigraphy. The morphology of the crater indicates that the third tephra deposit is a tuff ring formed around a maar, the crater of which was filled by basalt flows.

An evolution in the paleohydrologic conditions in the sedimentary basin at the time of the hydrovolcanic eruptions is inferred by the progressive changes in the characteristics of each successively younger tephra deposit. Basalt hydrovolcanic eruptions occur either in settings that contain abundant ground and/or surface water as in the Eifel region of Germany (Lorenz, 1973) or where abundant ground and/or surface water can be shown to have existed in the past as in the High Lava Plains of central Oregon (Heiken, 1971; Allison, 1979). Lorenz (1973) noted that in the Eifel, maar deposits formed in the bottoms of fluvial valleys, whereas cinder cones formed where eruptions occurred on valley slopes or the tops of ridges. Wohletz and Sheridan (1983) indicate that tuff cones of Quaternary age were erupted in areas where surface water was located above the vent, whereas tuff rings typically formed in areas where surface water above the vent was absent. The tuff rings, however, required abundant surface or ground water that could enter the vent during eruption.

The systematic changes in the lithologic associations in the three tephra deposits of the Dry Creek area indicate evolving hydrologic conditions in the basin. The first deposit, a tuff cone, is interpreted

Table 1. *Approximate thicknesses and general characteristics of lithologic associations for the three tephra deposits*

Tephra unit	Lithologic association*	Thickness	General characteristics
Tephra 3	---	14 m	Aphanitic basalt flows up to 1.5 m thick interlayered with reddish-brown palagonite in layers of similar thickness. Basalt is locally invasive into block breccias along the east rim of the crater. Xenoliths of crystalline olivine basalt approximately 3 mm in diameter occur in the flows.
	3	25 m	Planar to cross-bedded, vitric lapilli tuffs. Grain sizes within beds are uniform but different from overlying and underlying beds. Bed thickness ranges from 1 to 30 cm. Pods and lenses of aphanitic basalt occur in disturbed materials on the north rim of the crater. Pods have chilled margins and radial fracture patterns.
	1	25 m	Chaotic mixture of blocks including basalt, scoriaceous basalt, and felsic volcanoclastic sediments occurring in a matrix of fine palagonitized basalt glass, felsic detritus, and lithic fragments. Veins of calcite and zeolites are common. Blocks are up to 2 m in diameter and have alteration rinds over 3 cm thick in clasts of nonvesicular basalt.
Tephra 2	3	30-50 m	Moderately to well-bedded vitric-lithic lapilli tuffs. Coarse-grained beds are up to 30 cm thick; granule-size clasts occur in beds outward from the vent where bedding thickness is up to 5 mm. Accretionary lapilli up to 1 cm in diameter are common in well-bedded materials. Large-scale cross-bedding occurs in the upper 10 m of the deposits near the vent area. Graded bedding occurs as fining-upward sequences, and load casts occur where coarse-grained layers occur over fine-grained layers.
	2	20-30 m	Massive, unsorted block-and-ash deposits up to 1.5 m thick interlayered with porous vitric lapilli tuff. Beds of lapilli tuff are up to 30 cm thick. Ballistic stones of dense and scoriaceous basalt form bedding sags in bedded layers. Ballistic stones are at least 12 cm in diameter. Accidental inclusions include purple-gray rhyolite, dense basalt, and scoriaceous basalt.
Tephra 1	3	6+ m	Large-scale, low-angle cross-bedding to tabular cross-beds up to 1 m thick occurring near the top of the deposits. Cobbles up to 10 cm in diameter occur in matrix-supported to clast-supported, discontinuous conglomerate beds that are up to 35 cm thick. Cobbles are basalts of various textural types. Small felsic chips are locally present. Bedding types and lithologies include planar-bedded conglomerates and tabular cross-bedded, laminar, and low-angle large-scale cross-bedded siltstones to coarse-grained sandstones.
	2	40+ m	Block and ash-flow breccias overlain by large-scale cross-bedded deposits. Block and ash-flow breccias are up to 1.5 m thick, and cross-bedded materials are up to 2 m thick. Channels are common. Unsorted, massive block and ash units are also present. Poorly bedded, porous vitric lapilli tuffs display bedding sags produced by ballistic stones. One ballistic stone is over 1 m in diameter and produced a bedding sag extending 60 cm below the base of the clast.

\* See discussion on stratigraphy and lithology in text.





Figure 6. Three parallel beds containing accretionary lapilli from the second lithologic association in deposits of the second tephra deposit. The photograph shows the concentric layering characteristic of accretionary lapilli. The mechanical pencil is 11.5 cm long.

to have formed under conditions where abundant water was available. These conditions may have been met by eruption within a shallow lake or a broad, low-gradient fluvial valley characterized by high water tables and swampy conditions. The second deposit displays characteristics suggesting that throughout the eruption an adequate supply of water was available to produce violent hydrovolcanic explosions. However, the rate of water coming into contact with the rising magma decreased as the eruption continued (Fisher and Waters, 1970; Walker, 1984). The third deposit, a tuff ring around a maar, suggests that water did not enter the system at a fast enough rate to continue violent eruptions and that the eruption cloud was relatively dry. The dikes and irregularly shaped intrusions within the diatreme and the later eruption of basalt flows into the crater further indicate that magma output exceeded water inflow. Lorenz (1975, 1985) indicates that if the water supply is stopped during eruption, magma may enter the diatreme or be erupted into the crater.

This hydrologic evolution is also indicated by the felsic volcanoclastic sediments and basalt flows that are interlayered with the hydrovolcanic deposits. The sediments between the first and second tephra deposits indicate that a lacustrine environment was established immediately after eruption of the first tuff cone. These sediments grade upward into cross-bedded fluvial deposits that immediately underlie the deposits of the second tuff cone. The lignite deposits that immediately overlie the deposits of the second tephra deposit and the extensive deposits of the backswamp facies suggest abundant ground water but potentially no standing bodies of water, such as lakes. Immediately below the sequence of 12 basalt flows, small- to medium-size channel and levee facies are more common. A lake apparently developed in the area of Dry Creek, since the lower basalt flows of the sequence that overlies these sediments form a pillow-palagonite complex exposed in the cliffs along Dry Creek. The lower flows also have pillowed bases along Dead Horse Canyon, 1 km south of Dry Creek. However, pillows have not been observed in the lower flows south of Dead Horse Canyon. Fluvial sediments overlie the basalt flows. Cross-bedded, fine-grained sandstones and associated siltstones contain fish scales, and siltstones locally contain tree leaves. These sediments are believed to represent a moderately to well-drained landscape with stream valleys and low-relief interfluvies. The tuff ring of the third tephra deposit was deposited upon these sediments, and the maar and diatreme was cut into these sediments and the underlying basalt flow sequence. The progression in the volcanoclastic sediments corroborates the patterns of paleohydrologic evolution inferred from the characteristics of the hydrovolcanic deposits.



Figure 7. Subangular to subrounded rhyolite clasts (light-colored) within well-bedded vitric-lithic lapilli tuff. The clasts are typically less than 2 cm in length. These clasts are within surge deposits that are near the top of the deposits of the second tephra deposit.

The distribution, areal extent, and stratigraphic context of similar hydrovolcanic deposits in the Deer Butte Formation are, at present, unknown. The stratigraphy north of the Dry Creek arm overlies that portion of the stratigraphy that contains the hydrovolcanic deposits south of the Dry Creek arm. Although our map coverage north of Dry Creek extends for 1.5-3 km, the hydrovolcanic deposits are not present within this portion of the stratigraphic section.

However, hydrovolcanic deposits appear to be common within the stratigraphy of the area between Dry Creek and Red Butte and may be an important component of the lower portion of the Miocene Deer Butte Formation. The descriptions of measured sections between Dry Creek and the Red Butte area (Johnson, 1961; Kittleman, 1962; and Kittleman and others, 1965) suggest that hydrovolcanic deposits are present within this area. Evans (1986) reports basalt lahar deposits in stream valleys immediately southeast of Red Butte. Abbe and Cummings (1987) describe fissurelike features at least 1 km in length that have been infilled by felsic volcanoclastic sediments overlain by glass-rich basalt detritus, basalt blocks, and blocks of surrounding sedimentary rocks. These features were interpreted to have been dilatant fissures at the time of sedimentation and hydrovolcanic eruptions in the area.

Since hydrovolcanic eruptions require a specific set of hydrologic conditions, hydrovolcanic deposits (or their absence, where basalt flows are present) may provide a useful method of reconstructing hydrologic evolution of the sedimentary basin during deposition of the Deer Butte Formation. Whether the hydrovolcanic deposits are restricted to a particular stratigraphic interval within the Deer Butte Formation or occur at different stratigraphic levels will be investigated during further mapping.

Recognition of hydrovolcanic deposits and the presence of silicified and pyrite-bearing dikes within the diatreme of the third tephra deposit and color anomalies within the first tephra deposit draw attention to the economic potential of these deposits. Lorenz (1985) reviewed the characteristics of diatremes and briefly pointed out examples of economic mineralization found in these settings. The interaction of the erupting magma with ground water can produce diatremes that progressively migrate to deeper crustal levels as eruption continues. The diatremes may form to depths of 2-2.5 km below the surface. Wolfe (1980, 1986) examined diatremes associated with various forms of explosive volcanism. Hydrovolcanic eruptions at Taal volcano in the Philippines are examined as a mechanism for formation of breccia pipes. The hydrovolcanically formed breccias of the diatreme and crackle zones that extend into the country rock surrounding the diatreme are readily altered by

circulating hydrothermal solutions. The processes that produce economically mineralized diatremes and examples of precious-metal and base-metal mineralized diatremes are described in relation to the processes of formation.

Walden (1986) reports tuffs deposited by maar volcanism in the Miocene Sucker Creek Formation in the Coal Mine Basin area near the Idaho-Oregon border. D. Guilbert (personal communication, November 1987) reports possible basalt hydrovolcanic deposits southeast of Rockville near the Idaho-Oregon border. These reports suggest that basalt hydrovolcanic deposits may be present in several formations in the Owyhee region. The necessary hydrologic conditions to form hydrovolcanic eruptions apparently occurred at different times and in different parts of the Owyhee region throughout the Miocene.

## CONCLUSIONS

The presence of three basalt tephra deposits at three stratigraphically distinct levels within the felsic volcanoclastic sedimentary deposits exposed south of the Dry Creek arm of the Owyhee Reservoir suggests several conclusions.

1. Basalt hydrovolcanic eruptions were an important geologic process that accompanied felsic volcanoclastic sedimentation.
2. The first tephra deposit has characteristics of a tuff cone; the second of a tuff cone that grades upward into sediments more characteristic of tuff rings; the third tephra deposit is a tuff ring



Figure 8. Low-angle, large-scale cross-bedding within palagonitized vitric-lithic lapilli tuff of the second lithologic association. The photograph illustrates the deposits from near the top of the deposits of the second tephra deposit.



Figure 9. Photomicrograph of the basalt flows within the crater of the third tephra deposit. The basalt flows contain xenoliths of well-crystallized olivine basalt that are up to 3 mm in diameter. The nonporphyritic basalt flows contain a groundmass of extremely fine grain size. Field of view is 5 mm.

surrounding a maar. A series of basalt flows was erupted into this maar crater.

3. The changes in bedding, lithology, and lithologic associations among the hydrovolcanic deposits and the depositional environments represented by the interdigitated felsic volcanoclastic sediments indicate evolution in the hydrology of the basin during sedimentation. This evolution led from standing surface water and abundant ground water to moderate relief and less ground-water availability as sedimentation continued.

4. Basalt hydrovolcanic deposits are apparently common within the Deer Butte Formation exposed south of Dry Creek, but whether the deposits are restricted to a specific stratigraphic interval is still under investigation. Basalt hydrovolcanic deposits also appear to be common in the Miocene section of the Owyhee region.

5. The diatremes formed during hydrovolcanic eruptions are excellent targets for mineral exploration and should be examined with care.

## ACKNOWLEDGMENTS

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(Continued on page 94, Dry Creek)

# Well logging of oil and gas wells in Oregon

by Bill Diggon, Schlumberger Educational Services, 5000 Gulf Freeway, Houston, Texas 77252-2175

This is the second in 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. The first article, "Oil and Gas Exploration for the Nongeologist," by Wesley G. Bruer, appeared in the August 1986 issue of *Oregon Geology*. This second article tells how subsurface geophysical techniques are used to analyze oil and gas wells. Future articles, which will appear at irregular intervals in upcoming issues of *Oregon Geology*, will discuss such topics as leasing.

—Editor

## INTRODUCTION

Wireline logging has been used to analyze exploratory oil and gas wells in Oregon since the 1950's. These services are vital to the exploration and development process of Oregon's hydrocarbon resources. The following article describes how wireline logging serves the petroleum industry.

At the Mist Gas Field, most of the wireline logging is done by Schlumberger and Welx. Schlumberger owes its start to experiments in the early 1900's by Conrad Schlumberger, a French physicist, and his brother Marcel, a mechanical engineer, who demonstrated that electrical measurements on the earth's surface can map the earth's substructure. Later, in the twenties, they proved that measuring tools based on similar methods, when lowered into an oil well with an electrical conducting cable called a "wireline," could identify oil-bearing formations. This technique evolved into the business of "wireline logging," giving the oil industry the closest thing to an X-ray in the search for oil and natural gas. Today, Schlumberger and other oilfield companies assist in the drilling, location, production, and maintenance of oil and gas reservoirs.

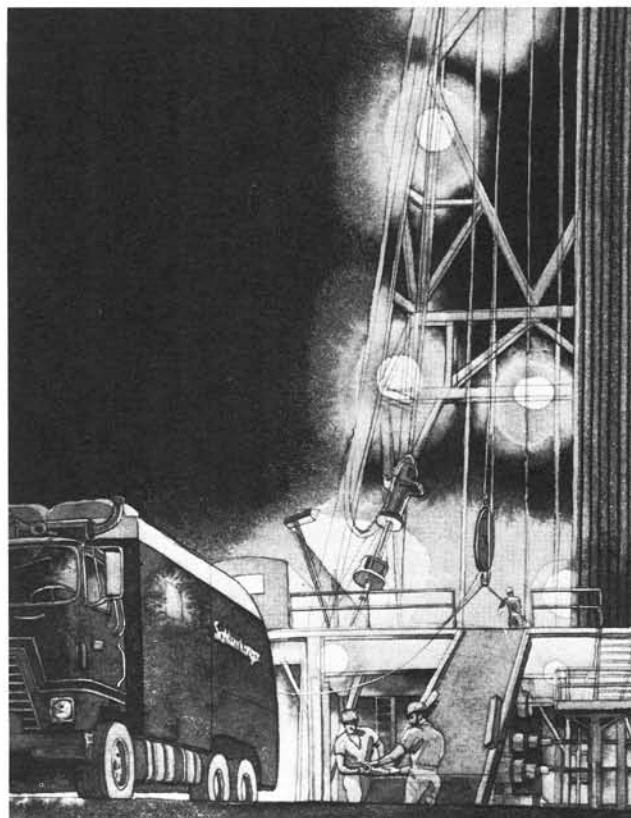
Once a promising geological area has been located by surface geological and geophysical surveys, a well is drilled. While drilling is in progress, a drilling analysis service, combining surface and downhole measurements, is provided to improve drilling efficiency and safety and to monitor hole direction. Periodically, drilling is interrupted to evaluate the well by means of wireline logging. When the logs indicate hydrocarbons, a drillstem test shows how much oil and gas will flow, confirming the discovery.

If results are positive, a heavy steel casing is cemented into the borehole to prepare the well for production. This casing keeps the hole from collapsing and isolates the productive formations. Then, explosive charges are detonated in the borehole, blasting cylindrical holes through the casing and cement deep into the productive zone, allowing oil and gas to flow into the well. For production, a length of small-diameter tubing is run inside the casing to the depth of the productive hole. Oil and gas flow to the surface through this tubing. When the rock formation is tight, fluids are pumped into the reservoir with enough force to split the rocks and open additional flow channels to increase production.

At this point, the production is tested at various flow rates, while pressure measurements are made downhole and at the surface. These data are needed to evaluate the production potential of the field.

The producing life of a well may span decades. At regular intervals, reservoir performance is monitored. Additional wireline logs are run and compared with the original logs to show changes in reservoir status.

Not all of the hydrocarbons in a reservoir can be produced by natural flow or pumping. Primary production may recover only part of the original hydrocarbons in place. Wireline logging assists in enhanced recovery techniques until the well is finally plugged and abandoned.



Preparing for a logging operation on a wellsite. The wireline cable is unwound from the truck onto the rig floor.

## A CLOSER LOOK AT WIRELINE LOGGING

When a well is drilled, very little information is available to the geologist standing at the top of a hole several thousand feet deep and only a few inches in diameter. He must be able to distinguish rock layers downhole that can be less than 6 in. thick. Often, there is scant evidence that the drill has penetrated an oil or gas reservoir. This is where wireline logging provides invaluable information.

Drilling is interrupted periodically so that a computerized mobile laboratory, called a "CSU," can lower measuring instruments to the bottom of the drill hole on an armored electrical cable called a "wireline." These instruments, encased in a slim cylindrical tool known as a "sonde," are then pulled slowly back to the surface, measuring continuously the physical parameters of the rock formations through which they pass. The data are transmitted on the



wireline to the CSU surface laboratory, where measurements are recorded on a magnetic tape and on a graph called a "log." Properly interpreted, these logs give a complete picture of subsurface formations—how deep, how thick, and how porous they are, and how much oil and gas they contain.

### WIRELINE TODAY

Today, wireline services are as vital to oil and gas exploration and production as the X-ray is to medical diagnosis. They now include electromagnetic, acoustic, and nuclear measurements and are recognized as the most reliable and scientifically accurate method for locating and evaluating oil and gas reservoirs. Yet, this service represents no more than 5 percent of the total cost of drilling a well.

Wireline services are needed throughout the productive life of a well. One category, openhole services, provides logging information in newly drilled wells. Production or cased-hole services, on the other hand, are offered after a steel casing has been set and cemented into the wellbore prior to production. In addition, the wellsite mobile laboratory provides a computer interpretation of downhole data at the well, thus facilitating decision making.

### LOGGING THE OPEN BOREHOLE

Downhole logging tools, the instruments that take the measurements, must withstand the "pressure-cooker" environment at the bottom of a well, where temperatures can exceed 400°F and pressures range above 10,000 psi.

Typically, the sonde crammed with sensors and electronics will consist of a cylindrical steel tube that is 20 to 40 ft long. The measurements record the physical properties of the rocks, their lithology, and their fluid content.

#### Electrical and electromagnetic measurements

An electrical current is sent into the formation, and resistance to current flow is measured. When the pores of a rock are filled with saltwater, the resistance to current flow is low; if they are filled with hydrocarbons, resistance is high. Thus, electric logs are the basic measurement for locating hydrocarbons. Sometimes oil is found with fresh water or low-salinity water whose resistance to current flow is also high, so another tool was developed to determine the proportion of water in pores of the rock, regardless of the salinity of the water. This is done through dielectric measurements using radio-frequency currents.

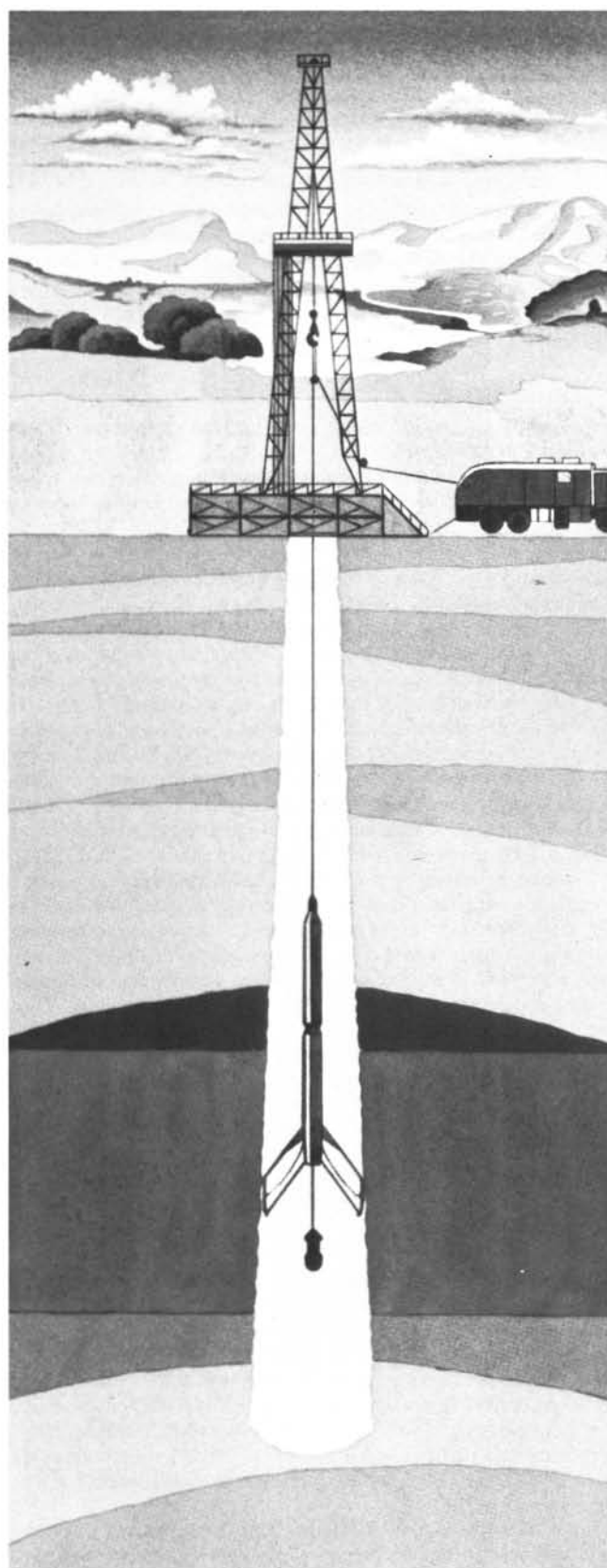
#### Acoustic measurements

Sonic tools transmit a sound wave and measure how long the sound wave takes to travel through the rock formations, how much of the signal is lost in transit, and how the shape of the wave has been modified. These measurements tell much about the structure and lithology of the rock, its porosity, and its fluid content. This information is used in formation evaluation, for fracture detection and completion design, and for refining surface seismic data through offset-seismic profiling. Acoustic signals at ultrasonic frequencies can resolve microstructures of rocks, while subsonic frequencies assist in borehole seismic investigations covering thousands of feet.

When high-energy sound waves are transmitted into the earth from the surface, they can be detected by a logging tool in the borehole. These downhole measurements provide information about geological structure at a great distance around and beneath the borehole. This technique, called "Vertical Seismic Profiling," is an important link between wireline logging data and the surface seismic exploration that precedes drilling.

#### Nuclear measurements

Nuclear tools investigate the atomic structures of rocks by measuring their interaction with nuclear particles. They help determine the lithology, porosity, and fluid composition of the formation. One of



*Periodically, drilling is interrupted to evaluate the well by means of wireline logging with a logging tool called a "sonde." When the logs indicate hydrocarbons, a drillstem test shows how much oil and gas will flow, confirming the discovery.*

these nuclear measurements detects natural formation radioactivity to locate shales. A second gauges the reaction of the formation to gamma rays or neutrons emitted by a source within the logging tool. The atoms of the chemical elements within rock, oil, and water react uniquely with the nuclear particles and indicate rock density and hydrogen content. Spectrographic analysis identifies elemental components of the formation.

### Stratigraphic information

Information gathered by another tool called a "dipmeter" helps define reservoir structure. Dipmeters combine multiple electrical resistivity measurements with gyroscopes and other "navigation" devices to measure the direction and angle, or dip, of each rock layer penetrated by the wellbore. They are also used to create "electrical images" of the borehole wall—similar to core photographs. These data help the geologist define the depositional environment of the field and can be crucial in determining where to drill the next well.

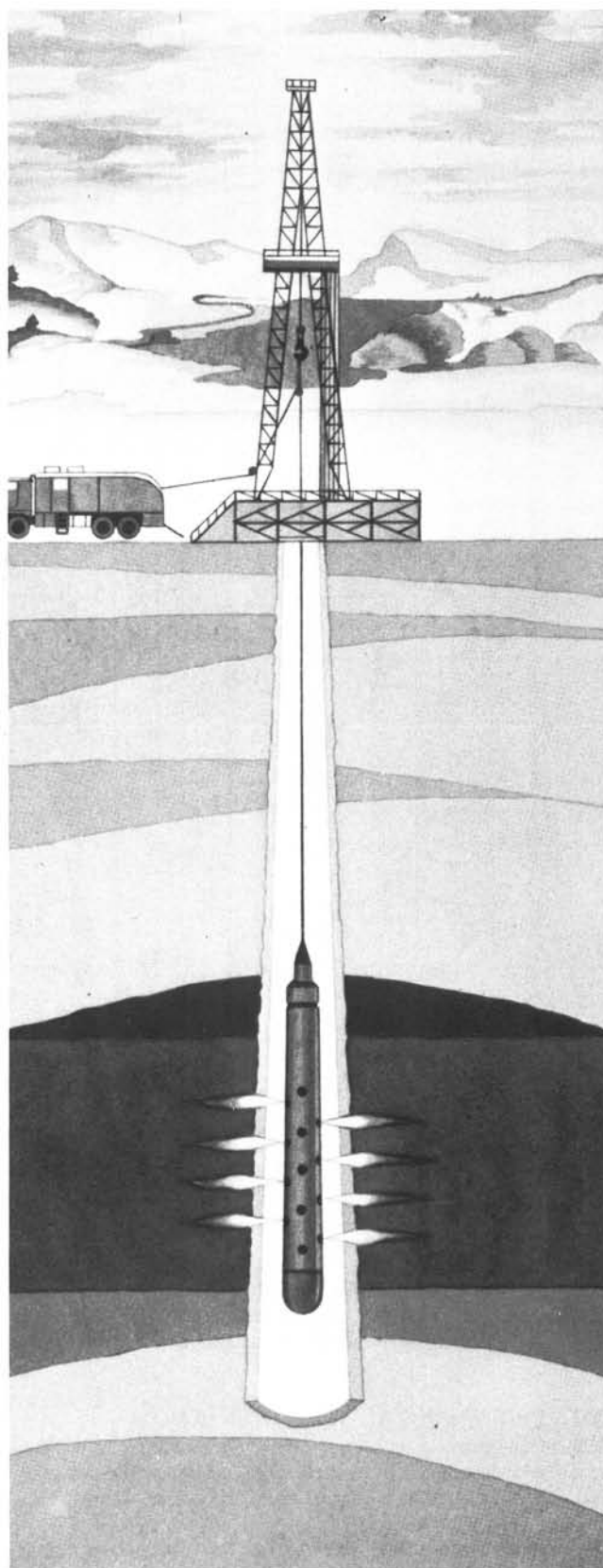
### Sample taking

Several types of wireline tools actually retrieve rock or fluid samples from the well for laboratory analysis. The Repeat Formation Tester, an advanced sample taker, collects fluids from reservoir rocks and measures formation pressure. The pressures at which these fluids enter the tool and the types of fluids recovered help define the ability of the formation to produce oil and gas.

### PROBING BEHIND THE CASING

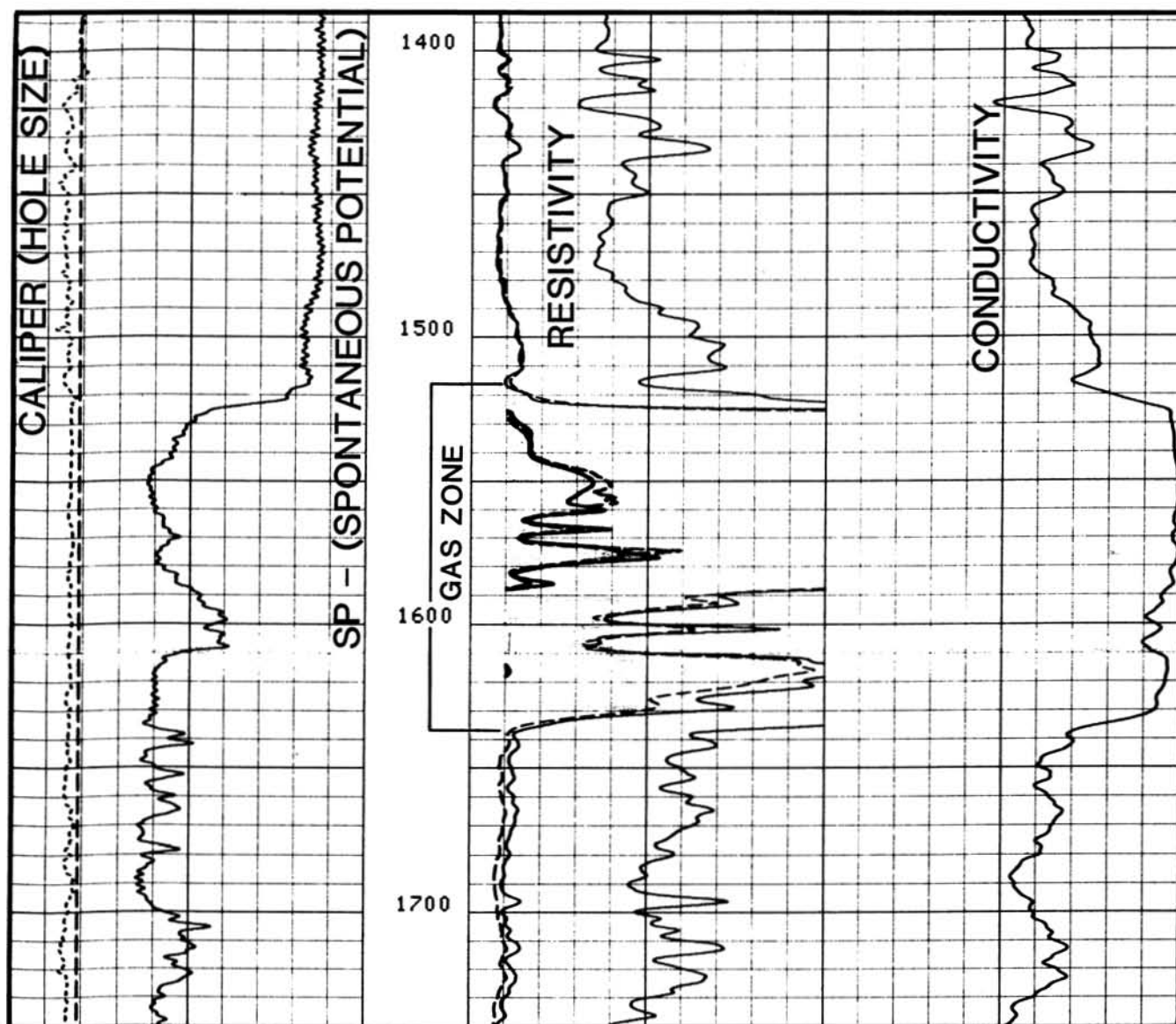
Once hydrocarbons have been located in commercial quantities, a steel casing is set from the surface to the bottom of the borehole and is cemented in place. This maintains the integrity of the wellbore and isolates productive formations from one another. Wireline services that are used extensively after holes are lined with steel casing are called "production" or "cased-hole services." Here are the most important applications for cased-hole services:

1. Bring a newly drilled well to production (well completion). Production services in a newly drilled well include the following:
  - a. Perforating by explosive charges that blast cylindrical holes through the casing and deep into the reservoir rock to allow oil and gas to flow into the wellbore and up to the surface.
  - b. Acoustic measurements that determine how solidly the casing is cemented into the borehole.
  - c. Base logs that determine the initial oil or water saturation so that, later in the producing life of the well, comparisons can be made with similar logs to monitor the movement of fluids in the reservoir.
  - d. Measurements made while the well is producing to determine how much each individual reservoir zone contributes to production.
2. Evaluate old wells. Wireline production services using acoustic and nuclear techniques can help locate behind-casing oil- and gas-bearing zones that were bypassed in wells either because no logs were recorded or because the logging program was insufficient.
3. Repair an old well to improve production (workover). After many years, producing wells can develop problems that require repairs. Again, wireline production services can determine the flow profile in the well and the water saturation behind the casing so zones producing unwanted water can be shut off. Also, acoustic measurements can check whether old cement in the annulus still provides an adequate hydraulic seal. Depending on the diagnosis, a workover program is set up. This could include wireline services to perforate the casing, either to squeeze additional cement into the annulus between the casing and rock formations or to produce oil and gas from remaining zones.
4. Monitor the performance of a reservoir. Wireline production services can be run periodically in producing wells to monitor the



*Perforating the well. Explosive charges are detonated in the borehole, blasting cylindrical holes through the casing and cement deep into the productive zone, thereby allowing oil and gas to flow into the well.*





Representative electric log from ARCO's Busch 14-15 well in the Mist gas field, showing the gas zone in the Clark and Wilson sand. Horizontal lines indicate depth. Vertical lines record electrical properties of fluids in the pore spaces of the rock. These properties indicate probable location of hydrocarbons.

performance of the reservoir and the effectiveness of the well completion. Flow, saturation, and pressure profiles are measured to show remaining reserves, water encroachment, and reservoir production efficiency.

#### DATA PROCESSING AND INTERPRETATION

In an interactive process requiring an interpretation expert, data acquired by downhole logging tools are translated by computers into useful parameters such as reserves, fluid content of formations, lithology, and rock porosity.

There are two primary levels of data processing and interpretation. The first is at the wellsite for immediate decision making; the second, at field log-interpretation centers or in offices, provides more in-depth analysis of the field data. Communications by satellite transmission between the logging truck at the wellsite and the log data processing centers bring together these levels of analysis and

permit well operators away from the scene to participate in wellsite decisions.

#### CONCLUSION

The role of wireline logging in the petroleum industry has been primarily formation evaluation in which the fundamental questions to be answered are the location of hydrocarbon-bearing formations and an estimation of the amount of hydrocarbon in place. A variety of downhole measurements yields answers to the questions in both open and cased holes. Today, the emphasis in the oil and gas industry is on using cost-effective technologies to maximize production from reservoirs and establish the most economical means of managing reservoir reserves. Wireline logging services contribute to every step of reservoir development from seismic surveys to the final reservoir engineering. □

# Mysterious blowhole near Black Butte Ranch

by Larry Chitwood, Geologist, Deschutes National Forest, 1645 Highway 20 East, Bend, Oregon 97701

On December 26, 1987, a cross-country skier discovered a cloud of steam rising out of a small hole in the ground. The area around the hole appeared to have sunk. The site, on Deschutes National Forest land (sec. 16, T. 14 S., R. 9 E.) is near Black Butte Ranch (see location map on next page). The parents of the skier, residents of Black Butte Ranch, immediately contacted the Sisters District Ranger, who quickly convened a small group including this author to look at the site.

Under 4 in. of snow, an area of about 25 ft by 50 ft had subsided by up to 3 ft. Within this area were three holes or pits, each about 3-4 ft across. One (the northernmost) was gently blowing warm, moist air of 58°F into the cold winter air of 25°F, producing a small cloud of condensed moisture. Depth of the blowhole was 7 ft, but since the top of the hole had subsided 2 ft, total depth was 9 ft. Foundering slabs of frozen soil 4-8 in. thick produced a miniature landscape of ridges, steep slopes, cracks, and tilted small trees.

The site was notable for supporting a thick concentration of 6- to 8-yr-old ponderosa pines growing in a strikingly rectangular pattern of about 25 ft by 80 ft. The subsidence area and holes were within this rectangle. Timber harvest in the late 1970's removed most trees at this site and in the vicinity.

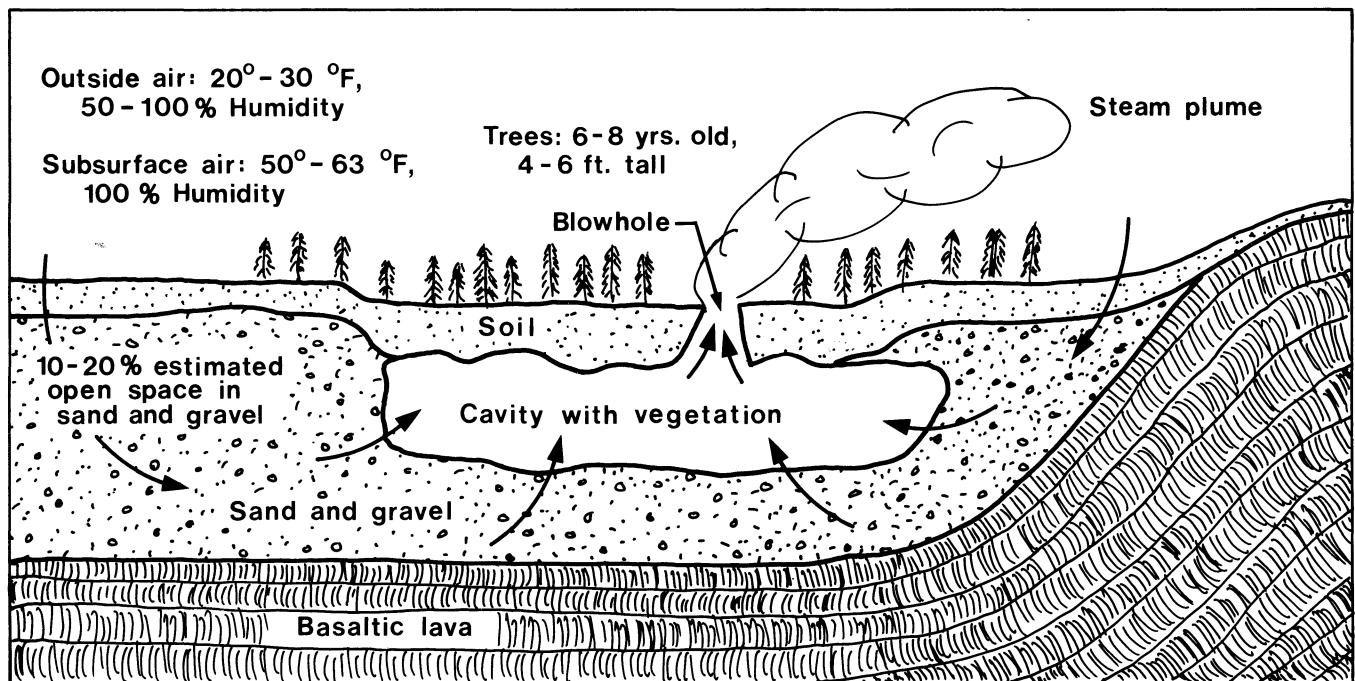
The area is a late Pleistocene basaltic lava field of low hills, with sand and gravel filling in many of the low areas of the field. During the latest Wisconsin glaciation, outwash rivers from glaciers north of the Three Sisters flowed through the low areas of the lava field and deposited sand and gravel. The subsiding area is within one of these deposits of sand and gravel.

During several weeks of observing and monitoring, the blowhole attracted the most attention. The steam plume and thick coatings

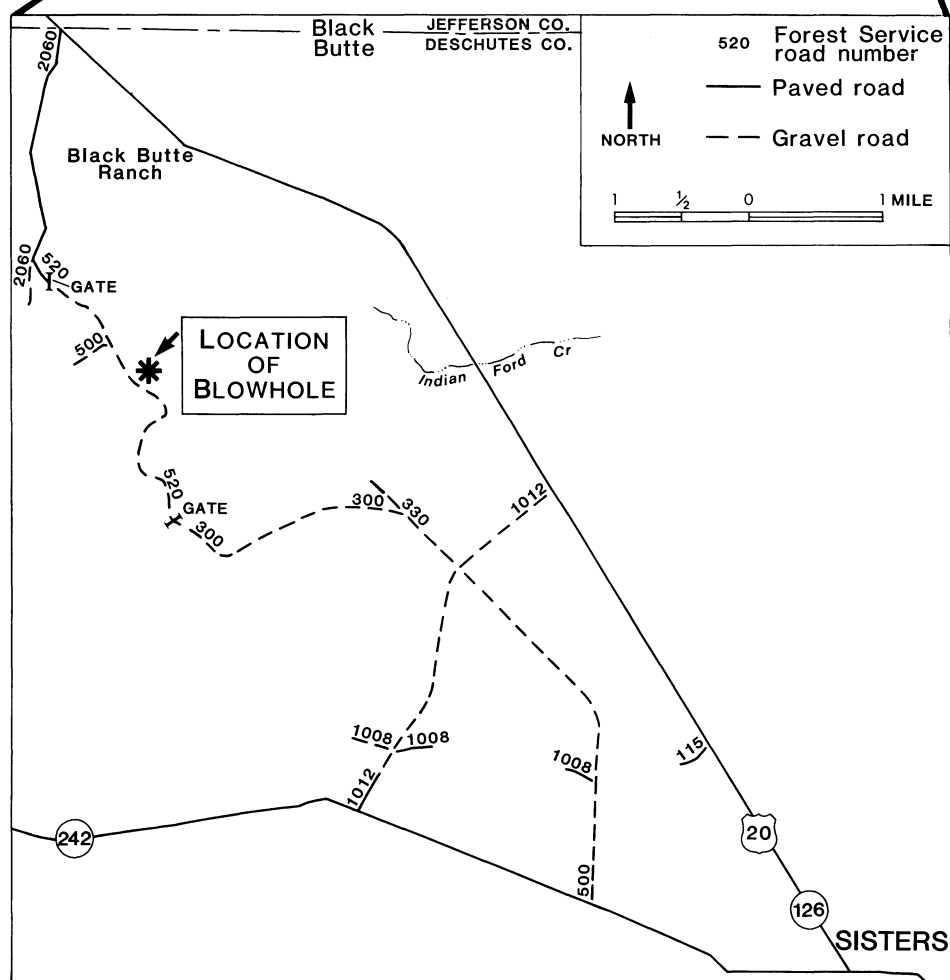
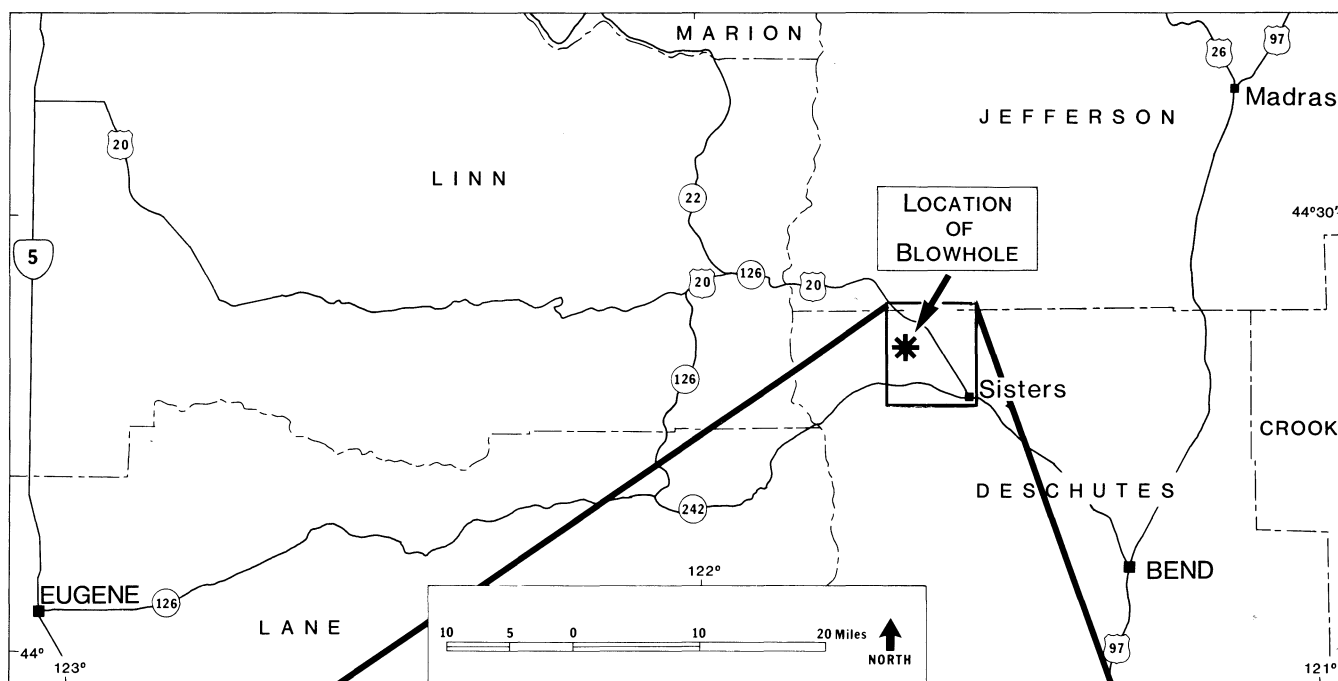
of frost on the small pines demonstrated high humidity of the underground air. The air smelled slightly of moist, organic soil. Temperatures of the air were recorded regularly for several weeks and ranged from 50° to 62°F. A startling temperature of 67°F, which was reported on January 4, 1988, prompted a quick trip to the site to discover that the glass tube of the thermometer suspended in the blowhole had slipped upwards in its frame by 10°. An air sample taken on January 5 and analyzed by Century Testing Labs of Bend, Oregon, indicated atmospheric composition: oxygen, 20.8 percent; carbon monoxide, <20 ppm; and carbon dioxide <0.2 percent.

During visits by several people, the blowhole was always observed to be blowing, never drawing. The volume of air flowing out varied from almost imperceptible amounts to an estimated 1,000 ft<sup>3</sup> per minute. This is contrary to the flow of air usually observed in caves and water wells in central Oregon. These routinely blow and draw due to changes in atmospheric pressure. When underground air space is large, the pressure within this space attempts to equilibrate with that of the atmosphere through wells and cave openings. Barograph records from December 29, 1987, to January 6, 1988, showed that atmospheric pressure was highly changeable. Consequently, airflow at the blowhole was independent of barometric pressure, indicating that the underground air space accessible through the blowhole was small.

The origin of the subsidence and blowhole had to relate to the existence of subsurface cavities in either (1) the sand and gravel, or (2) the underlying lava, or (3) both. The most likely possibility for creating cavities in sand and gravel is a man-made excavation backfilled with vegetation and soil. In lava, the most likely possibility at this site is a collapsing lava tube. Cavities in both the sand and



Schematic drawing of blowhole system, with arrows showing movement of air. Cool, dense outside air sinks into the ground over a wide area surrounding the blowhole and displaces warmer, less dense subsurface air in open spaces in sand and gravel. Subsurface air moves into vegetation-filled cavity and escapes through blowhole. Escaping subsurface air is saturated with moisture (100 percent humidity). In cool outside air, moisture condenses into steam plume. No steam plume was observed when outside air temperature exceeded 40° F. Data collected January through March 1988.



Map showing location of blowhole.

gravel and the lava could be tectonically induced: a deep crack or fissure could be opening. This possibility suggests impending volcanic activity. All three possibilities were seriously considered, but impending volcanic activity was considered to be highly unlikely.

As the subsidence incident developed, people who visited the site began to express their desires for a preferred outcome of the investigation. Certainly the most popular was that of a collapsing lava tube. Here, imagination and scientific interest could be served simultaneously. The backfilled-excavation idea was not popular; it was untidy and suggested unfinished business. The prospect of volcanism was most unpopular and frightening, since the site was very close to a developed area.

Only after snow melted from the site in February was the origin of the subsidence and blowhole confirmed. Fresh, gray, unweathered clasts of gravel were scattered over the entire surface of the 25-ft by 80-ft area that was so clearly marked by the rectangle of young trees. On the surface beyond the rectangle were yellow to tan gravel clasts typical of the upper 3 ft of soil in this area. Clearly, the subsidence site had been excavated to a depth of at least 9 ft, backfilled most likely with logging slash (tree branches, limbs, and tops) and/or stumps, then thinly covered with a homogenized mixture of topsoil, sand and gravel. The thin covering of soil had collapsed into the open spaces of the buried vegetation. The rectangle of young trees marks the excavated area, and the trees germinated and thrived in the disturbed soil. The subsidence occurred only days or weeks before December 26, because the ground had only recently frozen

and had subsequently broken up during subsidence.

When the blowhole formed, it acted like a chimney; in fact, one might call it an artesian air well. The relatively warm, moist underground air rose out of the hole into the cold winter air to form a thin steam plume. Air escaping from the hole was probably replaced by air drawn from the moist, fine web of interstitial passages in the surrounding sand and gravel. This local circulatory system was too small to be affected by barometric pressure changes but large enough to provide sustained heat from past summers to drive the convecting system.

Thus, several weeks of systematic observation brought the puzzle of the blowhole to a conclusion that neither satisfied the most popular expectations nor supported imaginative ideas of a frightful volcanic eruption. The blowhole was indeed the result of the imperfect backfilling of an old excavation and did not represent a threat to anyone.

Residents of central Oregon are generally aware that the remarkable landscape of this area was produced mainly by volcanism and glaciation. Occasionally, when a weather front approaches the Cascades, people are quick to notice "banner clouds" at the tops of volcanic peaks. These give the striking appearance of a steam eruption in progress and, far away as they are, inspire imaginative visions of volcanic activity. But when strange clouds rise in one's own backyard, concerns are immediate and serious and need responsible actions and answers. □

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## Watershed enhancement progresses

The 1987 Legislature created the Governor's Watershed Enhancement Board and provided it with \$500,000 in grant money. The money is to be used during a two-year period to help Oregonians improve severely degraded streamside areas and associated uplands. One of the criteria for funding is that a project would demonstrate the benefits of watershed enhancement to the public. Benefits can be decreased streambank erosion, improved water quality, and, in some areas, the return of year-round streamflow.

With its meeting in May, the Board concluded the grant award period; applications for funding improvement projects are no longer accepted. The Board received 60 applications from private individuals, organizations, and government agencies and, since February 1988, has awarded over \$370,000 to 17 projects. The Board will request additional grant money from the 1989 Legislature for continuing the program through 1991.

The following describes the five projects approved for funding at the Board's May meeting:

1. The Lakeview Soil and Water Conservation District plans to rehabilitate 6 mi of the Chewaucan River above the City of Paisley in Lake County. The Chewaucan River is tributary to Lake Abert. The project includes juniper and rock riprap, instream rock placement, vegetation planting, and a livestock control program. The project is an extension of similar improvements completed by the USDA Forest Service and the Oregon Department of Fish and Wildlife on other reaches of the river. State, federal, and local agencies and the landowner are cooperating in the project. Volunteer labor will be provided by the Paisley Future Farmers of America. Funds granted are \$21,700.

2. The Siskiyou Wheelmen, a volunteer group, will rehabilitate a road bank severely degraded by motorcycle and bike riding. The group, in cooperation with the USDA Forest Service, will place physical barriers on the cut slopes to minimize the amount of sedi-

ment flowing into the Ashland Creek watershed and into Reeder Reservoir. The reservoir is the City of Ashland's municipal water supply. Funds granted are \$1,450.

3. The U.S. Bureau of Land Management will implement a livestock management program to exclude cattle migration into the Whitehorse Creek basin. The project site is in southeastern Oregon near the border of Malheur and Harney Counties. Volunteer groups, such as the Oregon Natural Resources Council, the Izaak Walton League, Trout Unlimited, the National Wildlife Federation, and the Wilderness Society will provide up to 60 percent of the installation work. Funds granted are \$18,000.

4. The Lincoln Soil and Water Conservation District will carry out a project that is part of the 1987 Devil's Lake Coordinated Resource Management Plan. The project consists of fencing streambanks on Rock Creek to exclude cattle and allow riparian vegetation to become established. The riparian zone filters out and accumulates erosion sediments and nutrient runoff from Rock Creek which are major sources of pollution to Devil's Lake. Many government agencies, private landowners, and organizations are cooperating in the project. Funds granted are \$3,000.

5. The Grant Soil and Water Conservation District was given partial funding for its watershed enhancement project on the upper South Fork John Day River. The \$80,000 project is aimed at rehabilitation of 9 mi of stream to prevent erosion and includes fencing, vegetation planting, bank shaping, and structures for water management. The project also includes plans for fish habitat improvement and range improvement by brush control, fencing, and seeding. Funds granted are \$10,000.

The Board also has approved about \$43,000 for a public-awareness and education program. Planned for this program and aimed at a variety of audiences are speaking tours and slide presentations on watershed enhancement benefits.

—News release of the Governor's Watershed Enhancement Board

## Current deposition of metals on sea floor has ancient counterpart

Sulfides being deposited on the sea floor at ocean spreading centers are thought to be modern equivalents of on-land massive sulfide deposits formed tens to hundreds of millions of years ago and containing some of the world's largest deposits of base metals, according to a U.S. Geological Survey (USGS) scientist.

Sulfides are mineral compounds characterized by the linkage of sulfur with metallic elements. Many of the known on-land sulfide deposits have been mined for gold and silver.

"Modern-day analogs to these ancient deposits of copper, zinc, and lead may be currently forming along the ridge crests of spreading centers on the ocean floor, where Earth's crust is being pulled apart and volcanic material is welling up from below to fill the void," says USGS geologist Randolph A. Koski.

Spreading centers where sulfide deposition is occurring include areas in the U.S. Exclusive Economic Zone (EEZ) off the West Coast, such as the Gorda Ridge. U.S. jurisdiction over the EEZ was proclaimed in 1983, including rights to mineral recovery from the ocean floor.

Koski says that the study of how these modern sulfide deposits are forming could help in exploration for onshore deposits. "The study of modern sea-floor sulfides at mid-ocean ridges provides insight into the structural settings and hydrothermal processes that favor sulfide deposition," Koski says. "For instance, we now know that variations in occurrence and composition of these hydrothermal sulfides along ridge crests are largely controlled by sub-sea-floor porosity and structure as well as the nature of fluid-wallrock interactions." He explains that getting a better understanding of what causes and controls the deposition of sulfides on the ocean floors will give us a better understanding of how the now-onshore deposits were formed in ancient seas and what the best places are to explore for onshore sulfide deposits.

Koski is one of three USGS scientists each presenting a series of Bradley lectures at major USGS centers around the nation in 1988. He was selected for the honor by the USGS assistant chief geologist for the Western Region, with headquarters in Menlo Park, California. Similarly, two other scientists were selected as Bradley lecturers: Robert Schuster from the Central Region (headquarters in Denver, Colorado) and Bruce Wardlaw from the Eastern Region (headquarters in Reston, Virginia).

The lectures were named in honor of Wilmot Hyde Bradley, who worked for the USGS from 1920 to 1969 and who served the longest term, from 1944 to 1959, of any USGS chief geologist since the agency was established 109 years ago. The purpose of the Bradley lectures is to make USGS scientists and others aware of significant research and activities of the USGS Geologic Division.

—USGS news release

## UNR issues call for papers

The Mining and Engineering Division of the University of Nevada-Reno (UNR) Continuing Education Program has announced a symposium on engineering geology and geotechnical engineering and issued a call for papers.

The Engineering Geology and Geotechnical Engineering 25th Anniversary Symposium, sponsored by the UNR Civil Engineering and Geological Sciences Departments and the Division of Continuing Education, will be held March 20-23, 1989, on the UNR campus in Reno.

Papers are requested for the following topics: Waste management and design for nuclear and chemical waste; geophysical and in-situ

methods of site characterization; geotechnical applications of geostatistics and probability; engineering solutions to geologic hazards; earthquake engineering; foundation engineering; highway materials and pavement design; and case histories. Other topical areas of geotechnology will be welcome.

Preliminary abstracts (one-page limit) are due August 15, 1988, to Dr. Bob Watters, Proceedings Editor, Mackay School of Mines, University of Nevada-Reno, Reno, NV 89557, phone (702) 784-6069.

For further information about the symposium, contact Engineering Symposium, Division of Continuing Education, University of Nevada-Reno, Reno, NV 89557-0024, phone (702) 784-4046.

—UNR news release

## Coos Bay collection on display at State Capitol

The display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem is currently filled with an exhibit installed by Bert Sanne and Cecelia Haines representing the Far West Lapidary and Gem Society of Coos Bay. More than 100 separate items, all from Bert Sanne's own extensive collection, exemplify rocks from 11 Oregon counties.

Featured on the center shelves of the display case are a working rhodonite clock—pink rhodonite from Josephine County—and lighted lamps made from Carey plume and polka dot agate and encased in myrtlewood frames. The top shelves display Biggs jasper, Graveyard Point plume agate, Blue Mountain jasper, Crook County limb casts, and petrified-wood cabochons. Lower shelves show rough, tumbled, and faceted Oregon sunstones, Holley Blue specimens and two Holley Blue rings, sagenite, Paiute jasper, Vistaitite, thunder eggs from Crook, Wheeler, and Malheur Counties, Stinking Water Mountain wood, carnelian, and Eagle Rock and Friday plume agates.

The display will remain in place until September and will be followed by an exhibit furnished by the Trail's End Gem and Mineral Club of Astoria.

—OCRMC news release

## U.S. Geological Survey funds Oregon earthquake study

In March 1988, the Oregon Department of Geology and Mineral Industries (DOGAMI) was awarded a \$75,000 grant for the continuation of its earthquake studies through 1988. The grant comes from the National Earthquake Hazard Reduction Program that is administered by the U.S. Geological Survey (USGS).

"In recent months, the earthquake potential in Oregon has been increasingly in the news," said DOGAMI geologist Ian Madin, who works in the Department's earthquake study project. "This increased awareness in the public," he said, "reflects new geological research that suggests that earthquake hazards in Oregon may be greater than we previously believed."

The grant was awarded for the continuation of a multi-year, joint DOGAMI-USGS program begun in November 1987 with an initial grant of \$25,000. The program seeks to define and reduce earthquake hazards in the Portland metropolitan area through geologic research and mapping and by encouraging public and private hazard mitigation efforts.

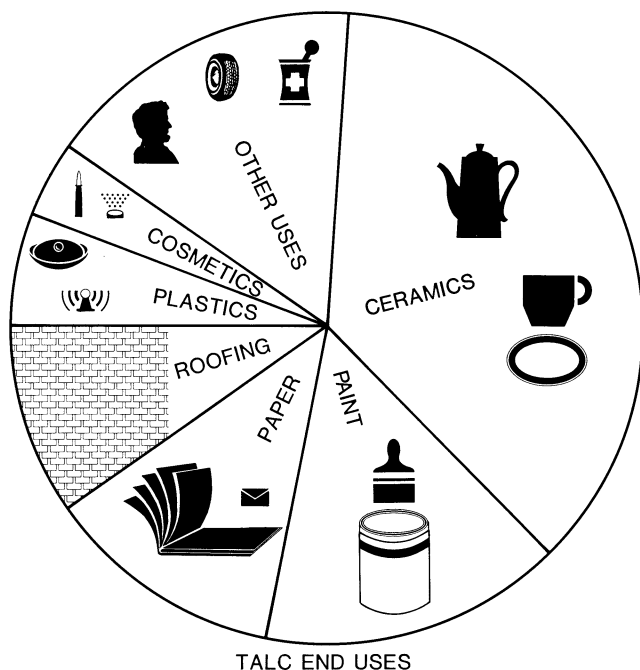
The program is planned to continue through 1991, and an additional \$300,000 in USGS funding is proposed for 1989-1991.

—DOGAMI news release



# First report on talc in Oregon available

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



Pie diagram from cover of Special Paper 18 shows industrial uses of talc.

*Investigations of talc in Oregon*, by DOGAMI geologists Mark L. Ferns and Len Ramp, has been released as DOGAMI Special Paper 18. It is the first comprehensive report devoted to this commodity alone and includes the results of two years of field study by the authors, as well as some information that so far had been available only in unpublished DOGAMI files. The 52-page report identifies and describes more than 100 separate talc occurrences in the state. Numerous tables present a variety of analyses of samples to characterize the deposits and their economic potential.

Until now, the only commercial use of Oregon talc has been the production of carving-grade soapstone. However, the report identifies occurrences that may have economic potential for other uses also.

The new report is now available at the DOGAMI office in Portland. The price is \$7. Orders under \$50 require prepayment.

—DOGAMI news release

## Oregon SMAC publishes user guide

The Geographic Information Systems (GIS) Committee of the Oregon State Map Advisory Council (SMAC) has published a guide for access to, and information about, organizations in Oregon that are involved in computer-stored geographic data.

*Oregon Geographic Information Systems User Reference Guide* is a brochure listing 28 federal, state, local, and private agencies and organizations, their addresses and contact persons; in addition,

it presents summaries of the kinds of computer hardware and software these organizations use, the geographic areas they cover, and the nature of the mapping data they generate. The list of participating organizations includes such bodies as, for example, the State Department of Transportation, the U.S. Army Corps of Engineers, Benton County Public Works, and Portland General Electric Company.

The guide was produced from information contained in the index to digital mapping data that is found under ORMAP in the Oregon State Library's on-line Public Access Catalog. It provides general information about an area of technology resources that changes continually and rapidly. With it, the GIS Committee hopes to promote the effective use of geographic information technology and to enhance the management of Oregon's natural and social environment.

More detailed information about ORMAP is available from Dick Myers, State Library, phone (503) 378-4368; and about hard-copy maps, aerial photography, and other indexes from Glenn Ireland, U.S. Geological Survey, phone (503) 231-2019. □

## Analyses of sediment-samples from continental shelf released

The elements titanium and chromium were among the most abundant of 26 elements analyzed in a study of sediment samples from the continental shelf off the coast of Oregon and northernmost California, according to a report released by the Oregon Department of Geology and Mineral Industries (DOGAMI).

*Elemental content of heavy-mineral concentrations on the continental shelf off Oregon and northernmost California*, by L.D. Kulm and C.D. Peterson of Oregon State University (OSU), has been released as DOGAMI Open-File Report O-88-4. It was funded in part by the U.S. Minerals Management Service through the Bureau of Economic Geology, University of Texas at Austin, Continental Margins Program, and administered by DOGAMI. Additional funding was provided by the OSU Sea Grant Program and the Oregon Division of State Lands.

The 29-page report presents the results of Instrumental Neutron Activation Analysis (INAA) of 73 sediment samples selected mostly from the OSU College of Oceanography archives. The samples had been taken from the top 40 centimeters of sand and mud sediments on the ocean floor in water depths between 17 and 200 meters.

According to the report, the highest chromium values, up to 7 weight percent of the opaque-mineral concentrate, were found on the inner shelf from Coos Bay, Oregon, to northern California. The largest quantities of titanium, up to 23 weight percent of the opaque-mineral concentrate, were found on the inner shelf between Tillamook and Cape Blanco, Oregon. However, the deposits have not been drilled, and complete evaluation would require deeper sampling.

Concentrations of heavy minerals, such as chromium-bearing chromite and titanium-bearing ilmenite, and of heavy metals, particularly gold and platinum, have been known to occur in coastal regions onshore as placer deposits and black sands. They were mined for gold as early as 1850 and for chromite and ilmenite in 1943, during mineral shortages of World War II. The concentrations of heavy minerals found in the surface sediments of the continental shelf suggest that there may be similar ancient beach placers deeper down in the shelf sediments as well.

The new release, DOGAMI Open-File Report O-88-4, is available at the DOGAMI Portland office. The price is \$5. Orders under \$50 require prepayment.

—DOGAMI news release

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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.*

**THE MESOZOIC STRATIGRAPHY, DEPOSITIONAL ENVIRONMENTS, AND TECTONIC EVOLUTION OF THE NORTHERN PORTION OF THE WALLOWA TERRANE, NORTHEASTERN OREGON AND WESTERN IDAHO,** by Patrick M. Goldstrand (M.S., Western Washington University, 1987)

Mesozoic rocks exposed along the Snake River in the northern Wallowa terrane represent portions of a volcanic island and associated intra-arc sedimentary basins within the Blue Mountains island arc of Washington, Oregon, and Idaho. In the northern portion of the Wallowa terrane, rock units include the Wild Sheep Creek, Doyle Creek, and Coon Hollow Formations, the Imnaha intrusion (informal name), and the Dry Creek stock (informal name).

The volcanic rocks of the Ladinian to Karnian Wild Sheep Creek Formation show two stages of evolution, an older dacitic phase (lower volcanic facies) and a younger mafic phase (upper volcanic facies). The two volcanic facies are separated by turbidites of the argillite-sandstone facies. The two magmatic phases that occur in the Wild Sheep Creek Formation may be represented by the compositional changes from older quartz diorite to younger gabbro in the Imnaha intrusion. The Imnaha intrusion may be a subduction-related pluton and is a likely source for the Wild Sheep Creek volcanic rocks. Interbedded with the upper volcanic facies are debris flows (sandstone-breccia facies) and carbonate platform deposits (limestone facies). Sedimentary structures in the Wild Sheep Creek Formation indicate a shoaling to subaerial volcanic island to the south and southeast.

The Karnian Doyle Creek Formation consists of epiclastic turbidites with interbedded vitric tuffs. Quartz diorite clasts in this formation indicate uplift and erosion of part of the Imnaha intrusion during the later emplacement of the gabbroic portion of the intrusion.

Between the Early and Late Jurassic (Oxfordian), the northern Wallowa terrane was uplifted and tilted. Clastic rocks of the Coon Hollow Formation represent transgression nearshore to offshore (sandstone-conglomerate facies) and progradational outer-fan to mid-fan environments (flysch facies). Radiolarian chert clasts in the flysch facies indicate a different source for this unit than the underlying stratified rocks of the Wallowa terrane.

Paleocurrent data and radiolarian fossils suggest that the Baker terrane was the source for the chert clasts. This chert source constrains the timing of the amalgamation of the Wallowa and Baker terranes to the Oxfordian. The amalgamation of these terranes during the Late Jurassic may be associated with initial accretion of the Blue Mountains island-arc complex with the western margin of North America. Uplift and extension was associated with this collisional event, and hornblende-diorite dikes and sills intruded the Wallowa terrane. After this intrusive event, compression and regional metamorphism to the lower greenschist facies occurred during the Late Jurassic. Also associated with the collisional event was the intrusion of a pyroxene-hornblende diorite stock (Dry Creek stock), which intruded the Wallowa terrane to shallow depths and has a K-Ar age of  $139.5 \pm 2.1$  Ma.

Accretion was complete by the Early Cretaceous with the suturing of the terranes of North America by plutons associated with the Wallowa Batholith. 130-Ma plutons which intrude the Blue Mountains island arc show  $66^\circ$  of clockwise rotation which may be related to Basin and Range extension.

Although the Wallowa and Wrangellia terranes formed in different tectonic environments, paleomagnetic and faunal evidence suggests a spatial relationship between the two terranes during the Late

Triassic. The Wallowa terrane may represent a volcanic arc originally situated to the east of the Wrangellia back-arc. If the terranes traveled with the Farallon Plate, the Wallowa terrane docked before and north of the Wrangellia terrane, and subsequent oblique convergence of the Kula and North American Plates initiated Sumatra-type strike-slip faulting to move Wrangellia outboard and northward of the Wallowa terrane.

**TEXTURAL AND MINERALOGICAL CHARACTERISTICS OF ALTERED GRANDE RONDE BASALT, NORTHEASTERN OREGON: A NATURAL ANALOG FOR A NUCLEAR WASTE REPOSITORY IN BASALT,** By Paul M. Trone (M.S., Portland State University, 1987)

Altered flows that are low-MgO chemical types of the Grande Ronde Basalt crop out in the steep walls of the Grande Ronde River canyon near Troy, Wallowa County, Oregon. The alteration effects in these flows are being investigated as a natural analog system to a high-level nuclear waste repository in basalt. The flows within the study are referred to as the analog flow, in which the alteration effects are the strongest, and the superjacent flow. The analog flow crops out at Grande Ronde River level, and a roadcut-outcrop is developed in the flow-top breccia of this flow. The two flows have been divided into flow zones based on intraflow structures observed in the field and primary igneous textures observed in this section. These zones include, from the base upward, the flow-interior, transition, and flow-top breccia zones of the analog flow, the interflow contact zone, and the flow-interior and flow-top breccia zone of the superjacent flow. The intraflow structures and textures of the transition and interflow contact zones are atypical of Grande Ronde Basalt flows. The transition zone is transitional in textures between the flow-interior zone and flow-top breccia zone and includes holocrystalline spines mantled with fused *in situ* breccias. The interflow contact zone reflects the dynamic interaction during the emplacement of the superjacent flow manifested as invasive basalt tongues; clasts shed from tongues, pipe vesicles, and tree molds; and pockets of breccia caught up in the base of the superjacent flow.

The characteristics of the porosity are distinct among flow zones. In the flow-interior zones the porosity is dominated by horizontal platy and vertical joint-related fractures. Vesicles and diktytaxitic cavities are a very minor contribution to the overall porosity and are somewhat isolated in contrast to the fractures, which are highly interconnected.

Low within the transition zone the porosity is similar to the flow-interior zone. High in the zone, the porosity includes vesicles in resorbed clasts and surrounding incipient breccia clasts. The porosity and extent of interconnection increases laterally outward from the spines in the fused *in situ* breccia as interclast voids increase in size and abundance.

The flow-top breccia zone and brecciated portion of the interflow contact zone are the most porous zones due to large interclast voids. Vesicles and diktytaxitic cavities are the porosity in these flow zones.

In the solid portion of the interflow contact zone the porosity is provided by platy fractures, large flattened vesicles, tree molds, and pipe vesicles.

Secondary minerals occur as replacements of primary phases and as precipitated phases in primary porosity. The variety of secondary minerals precipitated in vesicles and diktytaxitic cavities from aqueous solutions is greatest in the flow-top breccia and interflow contact zones and includes clay minerals, zeolites, silica minerals, and carbonate. The clay minerals include smectite and celadonite; zeolites include clinoptilolite, phillipsite, and chabazite; silica minerals include quartz, chalcedony, opal-CT lepispheres, and opal-CT; and the carbonate is calcite. The paragenetic sequence is clay minerals  $\rightarrow$  silica minerals  $\rightarrow$  zeolites  $\rightarrow$  carbonate  $\rightarrow$  silica minerals  $\rightarrow$  clay minerals. The individual mineral species differ among the

two flow zones. Celadonite, chalcedony, and quartz are the major secondary minerals in the interflow contact zone, whereas smectite, clinoptilolite, and opal-CT are the major minerals occurring in the flow-top breccia zone.

The differences in the secondary mineral suite, assemblages, and parageneses among the flow-top breccia and interflow contact zones are attributed to solution-composition differences. Assuming the basalt is inert to altering solutions, and the solution composition is not influenced by the relative proportions of glass and crystalline phases in the basalt or water/rock ratios, the differences in solution composition are reasonably explained if a thermal gradient is assumed present during alteration. A geothermal gradient, even if elevated above the assumed present-day gradient, is not sufficient to produce the alteration effects. An elevated gradient related to the cooling of superjacent flow is necessary.

#### **RADIOLARIA FROM THE OTTER POINT COMPLEX (OREGON) AND THE VOLCANO-PELAGIC STRATA ABOVE THE COAST RANGE OPHIOLITE (CALIFORNIA),** by Christopher L. Garey (M.S., University of Texas at Dallas, 1987)

Radiolaria from the Otter Point complex (southwestern Oregon) indicate that the unit ranges in age at least from late Kimmeridgian (Late Jurassic) to Berriasian-earliest Hauterivian (Early Cretaceous). The studied radiolaria, when analyzed from a paleolatitudinal perspective, indicate that portions of the Otter Point were deposited in near-equatorial waters. Many new radiolarian forms are presented and described from Otter Point cherts and limestone.

Radiolaria from the volcano-pelagic strata associated with the Coast Range ophiolite near Black Mountain, Sonoma County, California, indicate that the tuffaceous beds there are folded synclinally. The radiolaria were analyzed from a paleolatitudinal standpoint, and relative ages of the faunas from these analyses indicate the attitudes of the beds. All samples containing radiolaria from this locality were determined to be from Zone 2 of Pessagno (Kimmeridgian), and many new forms are presented and described.

#### **STRATIGRAPHY AND STRUCTURE OF THE WESTERN TROUT CREEK AND NORTHERN BILK CREEK MOUNTAINS, HARNEY COUNTY, OREGON, AND HUMBOLDT COUNTY, NEVADA,** by Scott Alan Minor (M.S., University of Colorado, 1986)

The area of study, which is 325 km<sup>2</sup> in extent, is located in the western Trout Creek and northernmost Bilk Creek Mountains along the Oregon-Nevada border, within the northwestern Basin and Range province.

The oldest rocks in the area consist of Cretaceous metamorphic and granitic intrusive rocks, which are nonconformably overlain by a 1,400-m-thick, 15.6-15.8-m.y.-old volcanic/pyroclastic sequence. More than 80 basaltic flows comprise the lower 750 m and, on the basis of a magnetostratigraphic study, have been correlated with the Steens Basalt. The upper part of the sequence primarily consists of four compositionally zoned ash-flow tuff sheets that vented from nearby calderas. The youngest (13.4-15 m.y.?) Tertiary rocks in the area consist of a thick (1,300 m) sequence of tuffaceous and conglomeratic sedimentary rocks.

A north-northwest-trending structural grain, which characterizes the study area, is expressed by numerous, closely spaced (<2 km), relatively large-displacement (1-3 km), north-northwest-striking normal faults and north-northwest-striking tilted fault blocks. Locally north-northeast-trending normal faults are present that truncate, are truncated by, or curve into faults of the other trend, indicating an equivalent age. Most of the north-northwest-trending faults dip from

25° to 60° at the surface, and many are inferred to be listric faults. Fault-to-bedding angles indicate that some of these faults were tilted to lower angle dips during deformation. Fault-slip data from small-displacement faults suggest that nearby major faults have experienced largely dip-slip displacement. The spatial distribution of tilted fault blocks, which dip as much as 60°, defines a broad, structurally disrupted anticlinal uplift with an axis that trends north-northwest and plunges towards the north-northwest. The directions of dip and the concavity of listric faults are toward the core of the anticline. Minor deformation occurred in the southwestern part of study area 15.8 m.y. ago during eruption of the basaltic flows. Major uplift and faulting occurred throughout the area about 14-15 m.y. ago; deformation may have continued intermittently up to recent time. Stresses associated with both the shallow emplacement of magma along a north-northwest-trending zone of weakness and Basin-Range regional extension may have caused the deformation.

#### **PALEOCURRENT ANALYSIS OF THE CRETACEOUS MITCHELL FORMATION, NORTH-CENTRAL OREGON,** by Craig A. Sandefur (M.S., Loma Linda University, 1986)

Cretaceous sedimentary rocks of north-central Oregon, known as the Hudspeth and Gable Creek Formations and here informally subsumed under the name "Mitchell Formation," are potential petroleum-source and reservoir rocks. Thus, determining their extent under the cover of Tertiary volcanic rocks is of great importance to future petroleum exploration in the southern half of the Columbia basin. The direction of sediment transport has been previously studied by several workers with contradicting results and conclusions. The primary objective of this research was to expand the paleocurrent analysis using both macro- and micro-fabric to provide additional evidence of sediment-transport direction. This information allows a better prediction of the extent, thickness, and petroleum potential of the marine Cretaceous rocks.

From field study of both sedimentary structures and gross lithology my work reconfirms that these sediments are part of a sub-sea fan complex consisting of fan-apron-facies turbidites and mudstones (Hudspeth mudstone facies) and channel-facies conglomerates and sandstones (Gable Creek sandstone-conglomerate facies). Sole marks, flute casts, pebble imbrication, and alignment of plant fragments indicate that sediment transport was generally from south to north into a northeast-southwest elongate basin. These results suggest that the greatest potential for petroleum production from Cretaceous sediments in north-central Oregon lies in restricted rift-type basins such as those in the surrounding area of Mitchell.

#### **MATURATION, DIAGENESIS, AND DIAGENETIC PROCESSES IN SEDIMENTS UNDERLYING THICK VOLCANIC STRATA, OREGON,** by Neil S. Summer (M.S., University of California-Davis, 1987)

Data from three drill holes in Oregon in areas where sediments are mantled by thick sequences of volcanic rocks suggest that the sediments were subjected to an unusual diagenetic history. Anomalous, near-constant maturation levels in sedimentary sequences over 4,000 ft thick indicate that the levels of thermal maturation in organic matter below the volcanic cover were sufficiently high to have generated hydrocarbons.

Study of the mineral diagenesis of these sediments shows that they have been transformed to low-grade metamorphic rocks equivalent to the zeolite facies. The diagenetic mineral assemblage, consisting of sphene, chlorite, illite, and quartz, is nearly constant throughout the drillholes studied and corresponds to temperatures of about 170°-190 °C. The consistency of the authigenic mineral assemblage in four different rock types can be interpreted to be the

result of the movement of geothermal fluids through the strata. A hydrothermal mechanism is considered to be the most effective form of thermal input. Isothermal temperature fields can result from the influx of heat from a perched geothermal aquifer flowing in an overlying porous stratum with the steady-state geothermal gradient. These isothermal conditions may have lead to the anomalous vitrinite-reflectance profiles and the common authigenic mineral assemblage.

The cooling of extrusive volcanic material and the exothermic hydration reactions associated with the altering volcanic material can also be considered viable mechanisms of thermal input, resulting in constant maturation profiles. The lavas and tuff could not only have supplied heat to the sediments upon cooling but could have provided aquifer horizons that allowed extensive lateral flow of thermal fluids. The most likely source of thermal fluids would be intrusive bodies possibly associated with a pre-eruptive, intrusive stage of Columbia River basalts. Thus heat from the intrusives would have caused regional effects that extended far beyond those of the solely conductive metamorphic effects.

Nearly all of the published and unpublished vitrinite reflectance data from sediments overlain by thick volcanic strata in Oregon and Washington have anomalous near-constant profiles. This implies a systematic phenomenon which has broad implications for oil and gas exploration in the Pacific Northwest. Relatively organic-poor sedimentary sequences may provide significant amounts of hydrocarbon due to the fact that much larger volumes of thermally mature rock are involved. In addition, migration vectors may be assessed by study of the fossil hydrology and authigenic mineralization of the volcanically-lidded basins of the Pacific Northwest. □

#### (Dry Creek, continued from page 82)

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#### (Oil and gas, continued from page 74)

withdrawal well is used to add gas to and remove gas from the storage reservoir. Oregon Natural Gas Development plans to drill five gas-storage wells at Mist this year.

In addition, ARCO began exploratory drilling at Mist during June, the start of a multi-well program planning six to twelve wells with depths generally of 2,000-3,500 ft.

#### Operations begin at Morrow County well

ARCO has begun drilling preparations at the Hanna 1 drill site located in the NE ¼ sec. 23, T. 2 S., R. 27 E., Morrow County, about 6 mi northeast of Heppner. This is a proposed 9,000-ft wildcat well in eastern Oregon's Columbia Basin and will drill through rocks of the Columbia River Basalt Group to test underlying Tertiary rocks which are interpreted to have favorable conditions for hydrocarbon generation and entrapment.



View south from Peak 3238, showing approximate drill site for the ARCO Hanna 1 well, 6 mi northeast of Heppner in Morrow County.

#### DOGAMI plans Tyee Basin natural-gas study

The Oregon Department of Geology and Mineral Industries (DOGAMI) plans to conduct a 5-year study of the natural-gas resource potential of the Tyee Basin in western Douglas and eastern Coos Counties. This area has geologic similarities to the producing Mist Gas Field area in Columbia County. The study will investigate the geologic factors in the Tyee Basin that are necessary for gas generation and entrapment.

#### Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
407	ARCO Columbia Co. 24-9-64 36-009-00241	SE ¼, sec. 9 T. 6 N., R. 4 W. Columbia County	Application, 2,260.
408	ARCO Claruth-Franbea-Willna 12-15-64, 36-009-00242	NW ¼, sec. 15 T. 6 N., R. 4 W. Columbia County	Application, 2,225.
409	ARCO Benson 14-7-64 36-009-00243	SW ¼, sec. 7 T. 6 N., R. 4 W. Columbia County	Application, 2,175.
410	ARCO CFI 23-16-64 36-009-00244	NW ¼, sec. 16 T. 6 N., R. 4 W. Columbia County	Application, 1,775. □



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