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IN THIS ISSUE:
Deschutes Basin field trip guide

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### Information for contributors

*Oregon Geology* is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. If manuscript was prepared on common word-processing equipment, a file copy on 5-in. diskette may be submitted in addition to the paper copies. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 6th ed., 1978.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

## Cover photo

Deschutes River Canyon near Steelhead Falls in Jefferson County. Late Miocene volcaniclastic sediments and ignimbrites of the Deschutes Formation form the cliffs on the right side of the river and in the background. Pleistocene intracanyon basalt flows form the prominent benches on the left side of the view and in the middle ground. Photo by Gary A. Smith. See related field trip guide by Smith beginning on next page.

## OIL AND GAS NEWS

### Mist Gas Field activity

Nahama and Weagant Energy Company began a multi-well drilling program at the Mist Gas Field, Columbia County, during October. The CER 11-16-64 well, located in sec. 16, T. 6 N., R. 4 W., was drilled to a total depth of 2,328 ft and was completed as a gas producer. The well is currently suspended, awaiting pipeline connection. The CER 41-21-64 well, located in sec. 21, T. 6 N., R 4 W., was drilled to a depth of 2,121 ft and is an indicated gas producer that is currently suspended waiting for production testing. The LF 13-35-65 well, located in sec. 35, T. 6 N., R. 5 W., was drilled to a total depth of 2,150 ft and was plugged and abandoned.

Northwest Natural Gas Company began drilling at the Mist Gas Field Natural Gas Storage Project during November. The well IW 33ac-3, located in sec. 3, T. 6 N., R. 5 W., will be an injection-withdrawal well in the Flora Pool.

ARCO Oil and Gas Company plugged a number of wells during October and November. These wells are depleted former producers and are no longer capable of gas production. The plugged wells are the CFI 12-1, LF 11-31-64, LF 23-36, LF 41-35, CC 11-34-65, CC 43-27, Busch 14-15, Foster 42-30-65, CC 4, CC 34-4-65, and LF 12-33.

### Civil penalty legislation proposed

During the 1991 legislative session, the Oregon Department of Geology and Mineral Industries (DOGAMI) intends to present a bill that will provide civil penalty authority to the agency as part of its regulatory authority. The bill would authorize DOGAMI to impose civil penalties for violations of certain provisions of statutes relating to reclamation of surface lands and conservation of oil and gas and geothermal resources. For further information, contact Dennis Olmstead at DOGAMI's Portland office.

### Recent permits

| Permit no. | Operator, well API number | Location | Status, proposed total depth (ft) |
|---|---|---|---|
| 451 | Nahama and Weagant<br>CER 14-16-64<br>36-009-00277 | SW¼ sec. 16<br>T. 6 N., R. 4 W.<br>Columbia County | Application;<br>2,500 |

□

## DOGAMI 1991 open house announced

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces its second annual Open House and Information Exchange Session. The event will be held February 6, 1991, from 2 to 5 p.m. in downtown Portland at the Standard Plaza Building, 1100 SW 6th Avenue, in 3rd-floor meeting rooms A and B.

This is an opportunity to visit with the entire staff of the Department and learn firsthand about the agency's current activities. Displays will provide information on geologic mapping, earthquake hazard assessment, mineral resource studies including gold and industrial minerals, natural gas assessments, mined land reclamation, and regulation of drilling. The Department's laboratory, publication section, and sales office will also be featured.

The Department invites all those interested in its work to come and meet with the staff and share the refreshments that will be served. The Standard Plaza Building is two and one-half blocks north of the Portland State Office Building. □

# A field guide to depositional processes and facies geometry of Neogene continental volcaniclastic rocks, Deschutes basin, central Oregon

*by Gary A. Smith, Department of Geology, University of New Mexico, Albuquerque, New Mexico 87131*

## INTRODUCTION

Sedimentary facies form a large part of the preserved stratigraphic record of most volcanic provinces. Study of volcaniclastic sequences adjacent to the Cascade Range has proven to be important for two reasons. First, in most parts of the Cascades, there is not a complete exposed record of Tertiary volcanism, and sedimentological and stratigraphic studies in adjacent sedimentary sections have contributed substantially to an understanding of the composition of extruded products, style of eruptive activity, and tectonic history of the arc (Smith and others, 1987; Smith and others, 1988). Secondly, pyroclastic volcanism generates large volumes of fragmental material over geologically instantaneous time intervals, resulting in highly episodic delivery of extraordinary sediment volumes to adjacent fluvial basins by a variety of transport and depositional processes involving a range of sediment concentrations and discharge characteristics. The types, distribution, and geometric relationships of the resulting lithofacies differ markedly from those illustrated by most alluvial sequences in nonvolcanic regions (Smith, 1987a,b, 1988, in press).

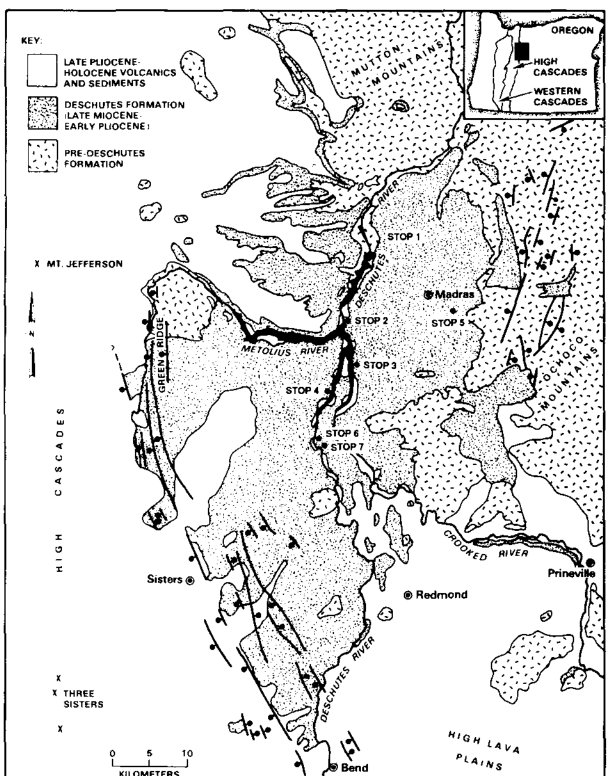



*Figure 1. Generalized geologic map of the Deschutes basin and adjacent areas showing locations of field-trip stops. Structures along the western margin of the basin include the late Miocene-Pliocene Green Ridge fault zone, locally bounding the central Oregon High Cascade graben, and the Quaternary Tumalo fault zone between Sisters and Bend.*

The purpose of this field trip is to illustrate the nature of synvolcanic sedimentation in a dissected Neogene fluvial basin. Emphasis is placed on (1) interpretation of depositional processes, distinguishing volcaniclastic materials emplaced by primary volcanic processes from those resulting from secondary sedimentary reworking, and (2) interpretation of volcanic and tectonic development of the central Oregon Cascade Range from examination of a primarily sedimentary record. The guide was prepared for an excursion to follow the 1991 Midyear Meeting of the SEPM, The Society for Sedimentary Geology, in Portland, Oregon. The reader is referred to Smith (1986b; 1987d; in press), and Smith and others (1987) for additional background information and to Robinson and Stensland (1979), Smith (1987a,b), Smith and Hayman (1987), and Sherrod and Smith (1989) for geological maps of areas included in this guide. Additional field guides describing this area include Smith and Priest (1983), Taylor and Smith (1987), and Bishop and Smith (1990).

## GEOLOGIC SETTING

The Deschutes basin is a broad valley extending from the Ochoco Mountains on the east to the Cascade Range on the west, and from the Mutton Mountains on the north to the High Lava Plains on the south (Figures 1 and 2). No structural margins to the basin are clearly defined. Late Cenozoic aprons of volcanic and volcaniclastic material extended eastward from the Cascades and onlapped older, mid-Tertiary volcanic highlands to the north and east. Deep dissection by the Deschutes River and its tributaries has exposed the largest of these aprons, represented by the upper Miocene to lower Pliocene Deschutes Formation (Figure 1) and, locally, middle Miocene sediments of the Simtustus Formation and associated flood basalts. These two stratigraphic units are the focus for the field trip. Older tuffs and rhyolite domes of the Oligocene to lower Miocene John Day Formation form conspicuous topographic features in the Mutton and Ochoco Mountains that are mentioned along the course of the trip.

## THE SIMTUSTUS FORMATION AND THE COLUMBIA RIVER BASALT GROUP

During the middle and late Miocene, 174,300 $km^3$ of basalt was extruded over a 163,700 $km^2$ area of eastern Washington, north-central Oregon, and western Idaho (Tolan and others, 1989). Approximately 90 volume percent of these Columbia River Basalt Group (CRBG) lava flows were extruded during the short time interval between 16.5 and 14.5 million years ago (Ma). The Deschutes basin lies just to the south and upslope of the margin of the principal flood-basalt province. Contemporaneous basalts were, however, erupted at unknown sites southeast of the basin and flowed northward through an ancestral Deschutes River valley to become intercalated with the other basalt flows farther north. Two flows of these local basalts occur in the Deschutes basin and have been assigned to the "Prineville chemical-type basalt" within the CRBG (Uppuluri, 1974; Smith, 1986c), although not all authors agree that the basalt of Prineville should be included in the CRBG (Goles, 1986; Reidel and others, 1989).

Over most of the vast region inundated by the Columbia River basalts are numerous but thin sedimentary interbeds that owe their origin, in part, to the disruption of drainage networks, locally raised base levels, and smoothing of relief resulting from flood-basalt

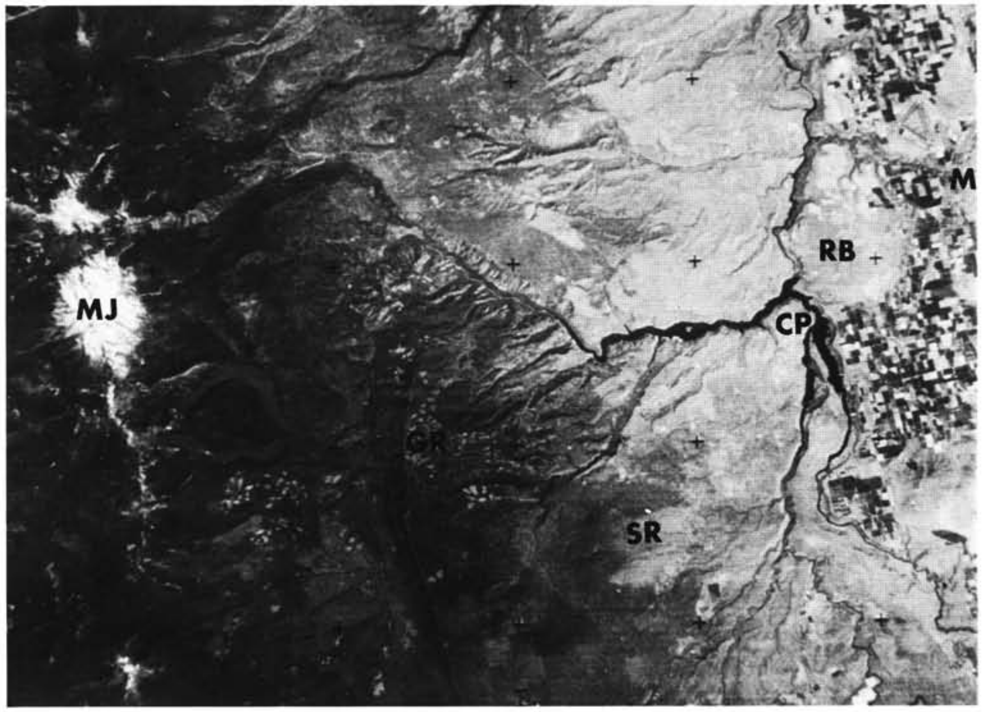



*Figure 2. Landsat RBV image of part of central Oregon showing the High Cascade Range on the west and Deschutes basin on the east; crosses are spaced at approximately 10-km intervals. MJ= Mount Jefferson; GR= Green Ridge fault escarpment; SR= Squawback Ridge, late Pliocene shield volcano; CP= The Cove Palisades State Park marking the confluence of (clockwise from upper left) the Metolius, Crooked, and Deschutes Rivers; RB= Round Butte, early Pliocene shield volcano; M= Madras.*

volcanism (Smith 1986b; Smith and others, 1989a). In the Deschutes basin, these sediments have been named the Simtustus Formation (Smith, 1986b). The Simtustus Formation consists of a discontinuous tuffaceous sandstone and mudstone interbed as much as 18 m thick between the two Prineville chemical-type basalt flows and an additional 5 to 65 m of similar lithologies that overlie the basalts in the Deschutes basin but appear to correlate to numerous sedimentary interbeds within younger basalts farther to the north (Smith, 1986b).

The relatively thin Simtustus Formation records modest aggradation of fluvial channels and flood plains in response to flood-basalt volcanism fed by fissure systems located 175 to 400 km east of the Cascade Range. The sediments are composed, however, principally of reworked pyroclastic debris supplied by Cascade Range volcanoes located upwind and immediately upslope to the west. The sediment is overwhelmingly dacitic and rhyodacitic in composition, although exposures of correlative rocks in the western Cascade Range are dominated by andesite and basaltic andesite lava flows (Priest and others, 1983; Smith, 1986b). This disparity reflects the preferential stripping of loose pyroclastic debris from proximal volcanic slopes and its consequent enrichment in adjacent fluvial sequences, relative to epiclastic sediment derived from the weathering of preexisting rocks.

## DESCHUTES FORMATION AND THE EARLY HIGH CASCADES

Following a 5- to 7-million-year (m.y.) hiatus, alluvial aggradation recommenced in the late Miocene with emplacement of the Deschutes Formation, a lithologically diverse assemblage of volcaniclastic sediments, lava flows, pumice-fall deposits, and ignimbrites. The Deschutes Formation represents a broad apron of primary and reworked pyroclastic debris that prograded eastward from the early High Cascade Range. This precursor to the modern High Cascades was a linear volcanic chain occupying the same location as the modern arc (Figure 3) (Taylor, 1981; Priest and others, 1983). The period of magmatism from about 7.5 to 5 Ma was characterized by voluminous extrusion of basalt and basaltic andesite lava and dacitic and rhyodacitic ignimbrites (Priest and

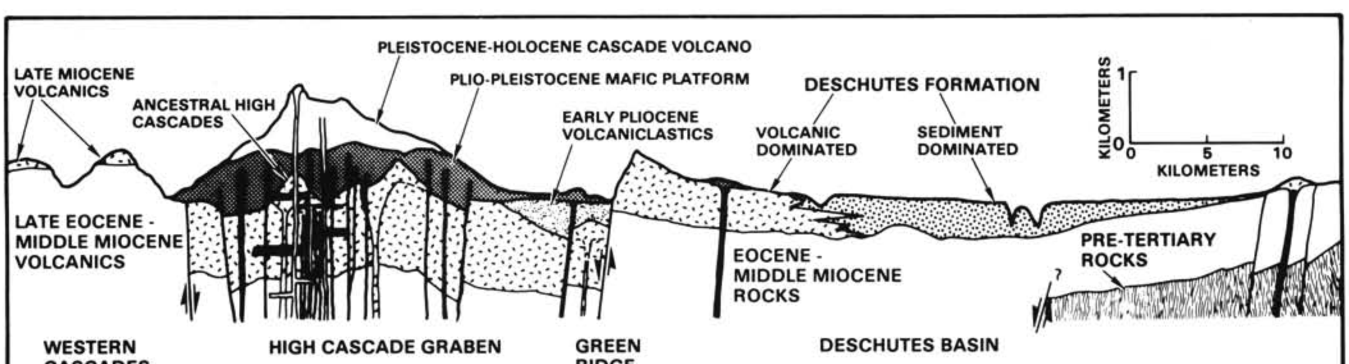



*Figure 3. Generalized cross section of the central Oregon High Cascade graben and Deschutes basin. Deschutes Formation volcanic and sedimentary rocks were largely derived from the ancestral High Cascades, now buried beneath younger volcanic rocks within the High Cascade graben. Interpreted structural truncation of pre-Tertiary rocks beneath the eastern Deschutes basin is based on gravity models of Couch and others (1982) and unpublished data by R.W. Couch and R.W. Foote (Oregon State University, 1986).*

others, 1983; Smith and others, 1987). The eruptive episode culminated in the collapse of the central Oregon High Cascades into intra-arc extensional basins (Taylor, 1981; Smith and Taylor, 1983; Smith and others, 1987; Smith, 1989). Green Ridge, which is located along the western margin of the Deschutes basin (Figures 2 and 3), is the eastern boundary of one of these basins. Proximal volcanic products are now buried from view beneath younger, principally mafic lava flows, leaving the Deschutes Formation as the only accessible record of this period of Cascade volcanism (Figure 3).

The Deschutes Formation ranges in thickness from about 700 m on the west to about 270 m in the center of the basin to an average of 20 m adjacent to the Mutton and Ochoco Mountains (Figure 3). Western outcrops of the Deschutes Formation are dominated by basaltic andesite and andesite lava flows representing the flanks of volcanic edifices that were truncated by the Green Ridge fault zone along the margin of the intra-arc depression (Figure 3). Basalt and basaltic andesite lava flows extended far into the Deschutes basin, where the section is dominated by coarse-grained sediments and the products of more than 100 ignimbrite-forming eruptions (Figure 3). Basalt flows were also erupted from vents within, east of, and southeast of the basin.

The sedimentology of the Deschutes Formation has been considered in detail by Smith (1986c, 1987d). Paleocurrent data and facies patterns define three depositional settings (Figures 4a and b), whose sedimentological characteristics are summarized below and whose representative sections are described at Stops 2, 4, 5, and 6.

### Arc-adjacent alluvial plain

The bulk of the Deschutes Formation was deposited on a broad alluvial plain that extended approximately 50 km from the Cascades to the center and, locally, eastern portions of the Deschutes basin (Figure 4a). Although ignimbrites, pumice- and ash-fall deposits, and lava flows, which are invaluable for stratigraphic correlation, are prominent constituents of the section, this portion of the basin fill is dominated by sediments.

The arc-adjacent alluvial plain stratigraphy is primarily composed of flood and debris-flow deposits (Stops 4 and 6). Flood deposits include abundant scour-and-fill bedded sheetflood and/or shallow-braided stream facies reflecting rapid aggradation by poorly confined, flashy flows, and normally graded, massive to crudely bedded hyperconcentrated-flow deposits (Smith, 1986a; Smith and Lowe, in press). Debris-flow deposits are massive and generally matrix supported and exhibit variable grading profiles (e.g., Walton and Palmer, 1988).

The flood and debris-flow deposits are arranged in broad sheets that are bounded by erosional surfaces with as much as 80 m of relief and paleosols. Rapid aggradation of pyroclast-rich sediments and dispersal of debris-flow and hyperconcentrated-flow deposits to distances in excess of 35 km from source, which is rarely seen in nonvolcanogenic alluvium, are interpreted as responses to eruptions that provided large volumes of fragmental material and considerably altered the hill-slope hydrologic systems to generate highly varying discharges. Deposition was, therefore, largely driven by eruptive activity, and inter-eruption periods were dominated by incision as streams reestablished normal profiles in the absence of the extraordinary sediment load and discharge variability of the syneruption periods (Smith, 1987c,d, in press; Smith and Vincent, 1987). The alternation of syneruption aggradation and inter-eruption degradation produced the distinctive facies geometry of flood and debris-flow deposits that form erosively bounded sheets locally capped by paleosols (Stop 6).

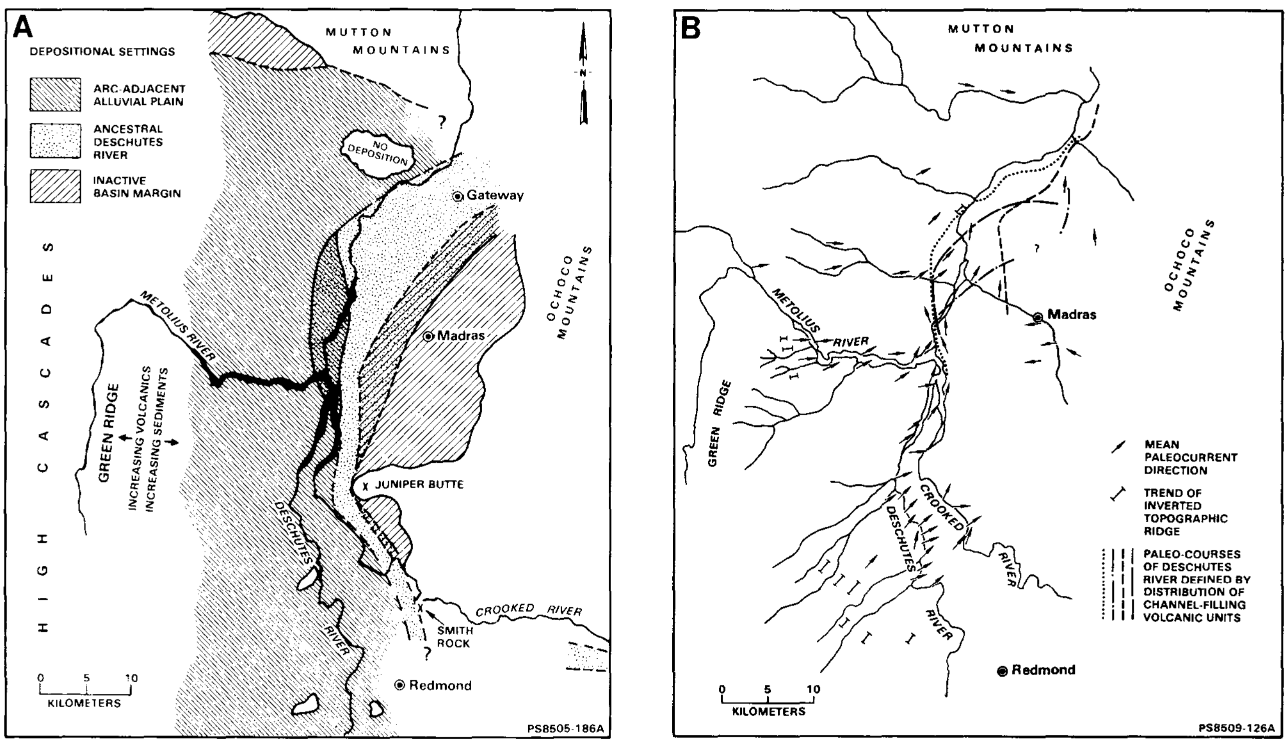



*Figure 4. A. Deschutes Formation depositional settings; see text for discussion. B. Paleocurrent data for the Deschutes Formation. Arrows show mean paleocurrent directions for the localities, based on channel orientations and cross-bedding. Bars show orientations of exhumed inverted stream channels filled with resistant basalt flows. Line patterns in the northern Deschutes basin mark the paleocourse of the ancestral Deschutes River, as indicated by distribution and thickness patterns of channel-filling ignimbrites and lava flows (based on mapping by Smith, 1987a,b; and Smith and Hayman, 1987). Both figures from Smith (1987d).*

More typical fluvial conditions are recorded by uncommon cobble conglomerates and associated sandstone and siltstone overbank deposits (Stop 4). These deposits are rarely more than 5 m thick and are restricted to broad valleys or channels that were incised into the more common flood and debris-flow facies. The conglomerates indicate deposition by gravel-bedload streams following incision during inter-eruption periods.

Inter-eruption aggradation is recorded only in the lower part of the stratigraphic section when basin subsidence adequately accommodated the sediment influx. The upper half of the section accumulated in only a few hundred thousand years in response to frequent, voluminous pyroclastic eruptions (Smith, 1986c; Smith and others, 1987). Accumulation outstripped the accommodation provided by modest subsidence. Hence, deposition of the upper half of the section occurred episodically only in response to volcanism, and inter-eruption periods were characterized by incision and regrading of stream profiles with little or no net deposition (Smith, 1987c, in press; Smith and Vincent, 1987; Smith and others, 1989b).

The Deschutes Formation alluvial plain was probably analogous to the ring plains associated with modern volcanoes in New Zealand (Hackett and Houghton, 1989; Smith, in press). Although the arc-adjacent alluvial plain facies association of flood and debris-flow deposits is characteristic of nonvolcanogenic alluvial fans, several observations argue against an alluvial-fan morphology for the western Deschutes basin (Smith, 1987c,d). Facies types do not vary greatly downslope, and abrupt lateral grain-size changes typical of alluvial-fan sequences do not occur in the Deschutes Formation. Paleocurrent data, largely determined from channel orientations and shoestring geometries of channel-filling lava flows and ignimbrites (Figure 4b), define a parallel to contributory drainage pattern, not the radially diverging and distributary patterns that define fans. The floods and debris flows that were generated in response to explosive volcanism episodically dispersed sediment to much greater distances than are typically seen in nonvolcanic settings where these facies are restricted to small, mountain-front alluvial fans (Smith, 1987c).

Deposition on the arc-adjacent alluvial plain virtually ceased when rapid subsidence of the intra-arc basin isolated the Deschutes basin from its Cascade Range source area (Figure 3). An abrupt transition from typical arc-adjacent alluvial plain facies to a 10- to 50-m-thick interval of superimposed sandy paleosols and pumice-fall tephras records this transition from a basin overrun with sediment and volcanic rocks to one that was virtually sediment starved (Smith, 1987d; Smith and others, 1987, 1989b). Cascade lava flows, ignimbrites, and related sediments were subsequently ponded in the intra-arc graben (Figure 3). Lava flows that do occur in the uppermost Deschutes Formation were erupted from vents within the Deschutes valley and from fissures coincident with the developing eastern faulted margin of the intra-arc depression.

### Ancestral Deschutes River

The ancestral Deschutes River flowed northward at the foot of the alluvial plain (Figure 4a). Extensive progradation of the southern part of the alluvial plain forced the axial stream against older Tertiary highlands on the east margin of the basin in an area of no present-day exposure. Ancestral Deschutes River deposits are, however, found adjacent to the modern river in the northern part of the basin. Well-rounded, moderately well-sorted, and commonly cross-bedded conglomerates and coarse sandstones record a largely gravel-bedload stream. These channel deposits alternate with a nearly equal volume of bioturbated massive to thin-bedded fine sandstones and mudstones representing overbank deposition. Pumice- and ash-fall, hyperconcentrated-flow, and rare debris-flow deposits occur with the overbank facies. Details of this facies association are described at Stop 2.

### Inactive basin margin

Deposition in the Deschutes basin was principally in response to Cascade volcanism that dispersed sediment eastward across most of the basin. Small watersheds did drain southward from the Mutton Mountains and westward from the Ochoco Mountains (Figure 4a). Deschutes Formation sediments exposed in and east of Madras are the most representative of this setting and consist of two components. The bulk of the sediments is composed of poorly sorted, angular gravel and sand derived from older Tertiary rocks of the Ochoco Mountains: mainly John Day Formation rhyolite clasts and, rarely, clasts of the basalt of Prineville. The second component is vitric pyroclastic debris of Cascade provenance derived from the reworking of ash-fall and pumice lapillistones that occur locally within the section. Sediment accumulation along these relatively inactive margins of the basin was very slow. The Deschutes Formation sections in these areas rarely exceed 20 m in thickness and exhibit abundant evidence of pedogenic disruption throughout, in the form of abundant burrow and root bioturbation and oxidation of the sediment to brown and orange colors (Stop 5).

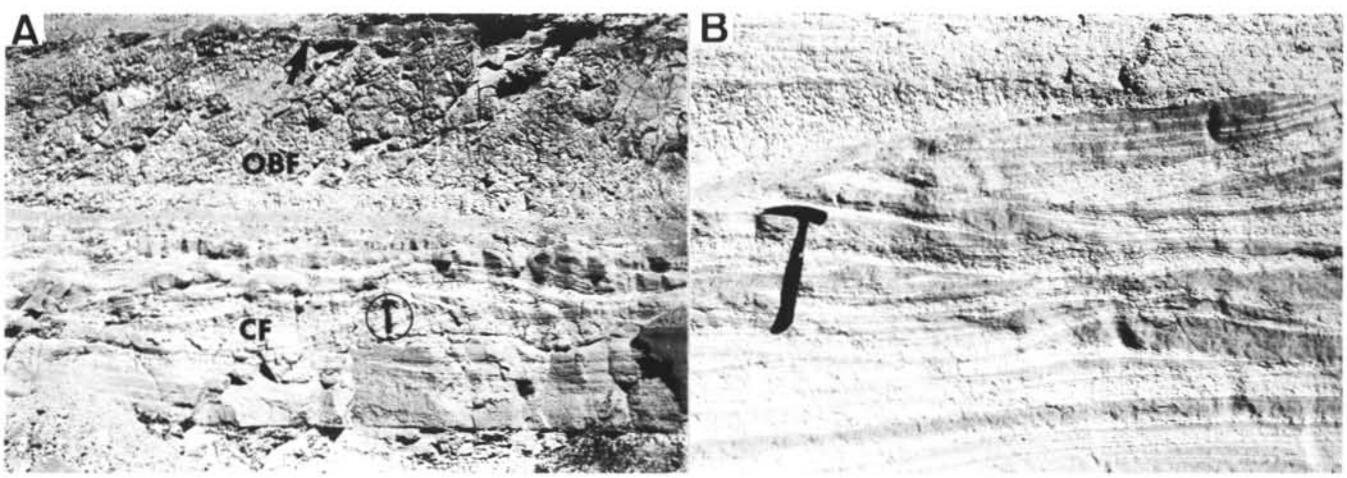



*Figure 5. Views of outcrops of the Simtustus Formation at Pelton Dam, Stop 1. A. Typical fining-upward sequence of trough cross-bedded channel facies (CF) and massive, blocky overbank facies (OBF). Arrow near top of photo points to base of accretionary-lapilli fallout tuff within the overbank deposits. B. Close view of trough cross-beds showing alternations of dark lithic-feldspathic sand and light tuffaceous silt suggesting unsteady flow during deposition.*

## DIRECTIONS TO STOP 1

The field guide for day one (Stops 1 through 5) begins at the intersection of U.S. Highways 97 and 26 at the north edge of Madras. Proceed northwestward on westbound U.S. 26 for 9.7 mi to the intersection with an unnamed road on the left (south side of Highway 26) that leads to Pelton Dam and Lake Simtustus. Turn left onto this road and continue 2.8 mi to Stop 1, at the eastern abutment of Pelton Dam.

## GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 1

Highway 26 climbs from Madras onto the Agency Plains. Sandstones of the Deschutes Formation occur in the road cuts near the junction with U.S. 97. The Agency Plains are underlain by a thin erosional remnant of Deschutes Formation sediments that rest on a 5.3-Ma basalt flow that originated at Tetherow Butte, about 40 km to the south of here near the village of Terrebonne. This basalt, with spectacular columnar joints, is well exposed where Highway 26 begins its steep descent to the Deschutes River. Road cuts along the grade in Campbell Canyon expose sedimentary facies of the Deschutes Formation. After turning off toward Pelton Dam, the road follows the top of the basalt of Prineville, affording views of road cuts in the overlying Simtustus Formation, before descending through the uppermost lava flow near Stop 1.

## STOP 1. SEDIMENTARY FEATURES OF THE SIMTUSTUS FORMATION

Pelton Dam is constructed against the lower of two thick flows of the basalt of Prineville. The upper flow and the intervening sedimentary interbed, assigned to the Simtustus Formation, are exposed in the adjacent road cuts. Although consisting almost entirely of pyroclastic fragments, the Simtustus Formation sediments closely resemble fluvial facies typical of nonvolcaniclastic alluvium. The base of the Simtustus Formation is a reworked tuff with abundant leaf fragments (Pelton flora of Ashwill, 1983), which crops out below the road. The remainder of the section is composed of fining-upward sequences of tuffaceous, cross-bedded volcanic sandstone and massive tuffaceous mudstone (Figure 5a). A fine conglomerate occurs immediately below the overlying basalt flow. Fining-upward sequences are typical of the Simtustus Formation within the central Deschutes basin and record a north-northeast-flowing, laterally shifting, mixed-load stream. Trough crossbeds contain many internal lenses of tuffaceous silt, suggesting very unsteady flows (Figure 5b). The massive pink to light-brown overbank deposits contain abundant dispersed pumice lapilli. In some respects, they superficially resemble unwelded ignimbrites because of their massive, pumice-rich character. Instead, they represent bioturbated fine-grained sediment that included hydrodynamically equivalent pumice and, in some case, pumice- and ash-fall deposits. The gradational bases to underlying structured sediment, rare preservation of original depositional features, and local abundance of plant seeds and vertebrate fossils (not seen here) are important features that allow distinction from texturally similar ignimbrites. A continuous brown layer (20 cm thick) within the pink overbank facies is a normally graded ash-fall deposit with numerous accretionary lapilli near its base (Figure 5a). The abundance of lithic fragments and fine-grained, angular ash shards along with accretionary lapilli suggest that this ash-fall was the result of a powerful phreatomagmatic eruption.

## DIRECTIONS TO STOP 2

Continue southward from Pelton Dam and follow the road on its winding route up and out of the Deschutes Canyon until it terminates at Belmont Lane, about 6 mi from Stop 1. Turn right (west) on Belmont Lane and proceed 2.1 mi to the entrance to Round Butte Dam. Continue to the project office, where inquiry should be made to visit the locality of Stop 2, which is represented in road cuts between the dam and the lower gate south of the office.

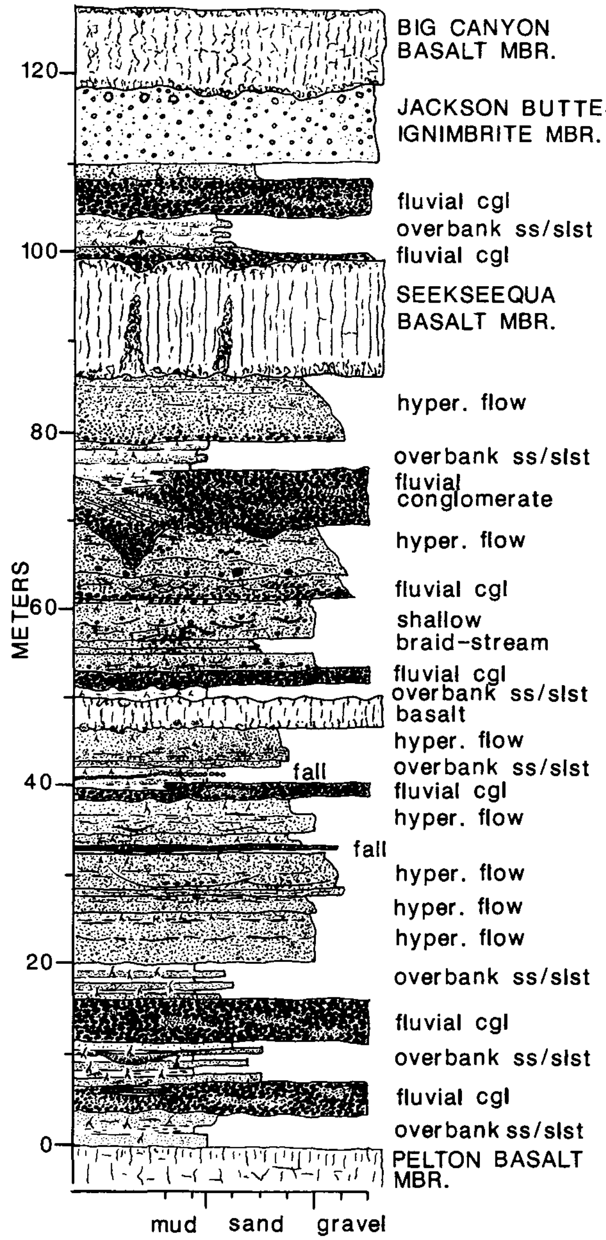



*Figure 6. Graphic measured section of the lower Deschutes Formation at Round Butte Dam, Stop 2. Ancestral Deschutes River sediments consist of conglomerates and related flood-plain sandstones and siltstones alternating with hyperconcentrated-flow deposits and less common flows and ignimbrites. Scour-and-fill bedded pebbly pumiceous sands suggesting flashy-discharge, shallow braided stream deposition occur at 55-60 m; this facies is more typical of the arc-adjacent alluvial plain setting and may have been deposited by a tributary to the main river. Cgl = conglomerate; ss/slst = sandstone/siltstone; hyper = hyperconcentrated.*

## GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 2

Road cuts south of Pelton Dam expose the basalt of Prineville and the Deschutes Formation. Excellent outcrops of the Deschutes Formation are visible in Willow Creek Canyon, about 2 mi beyond Pelton Dam. Landslides are common along the Deschutes Canyon; slope stability problems have forced the closure of the once popular

Pelton Park. Round Butte, a 3.9-Ma basaltic shield volcano (Snee, personal communication, 1985; Smith, 1986c) surmounted by a small cinder cone, looms to the southwest of the intersection of Elk Drive and Belmont Lane.

## STOP 2. ANCESTRAL DESCHUTES RIVER FACIES, DESCHUTES FORMATION

Road cuts along the east wall of the Deschutes River at Round Butte Dam provide the best exposures of Deschutes Formation deposits near the axis of the basin. The thick basaltic cliffs on the west side of the river are 1.2-Ma lava flows (Snee, personal communication, 1985; Smith, 1986c), that were erupted approximately 85 km south of here and flowed through the Crooked and Deschutes River canyons to a terminus represented by the bench that the utility project office is built on. The base of the canyon is cut into the Pelton basalt member of the Deschutes Formation, which has been dated at 7.42 ± 0.22 Ma (Snee, personal communication, 1985; Smith, 1986c). Based on stratigraphic correlations and isotopic dates (Smith, 1986c), that part of the section illustrated in Figure 6 is thought to represent about 1.6 m.y.

The late Miocene Deschutes River is represented by sandy conglomerate channel-fill facies and sandy and muddy overbank deposits (Figure 7a) that are intercalated with pyroclastic-fall units and hyperconcentrated-flow facies. The conglomerates are principally composed of well-rounded Cascade-derived volcanic clasts with varying proportions of John Day Formation rhyolite clasts brought from the Ochoco Mountains. Crude stratification, lenticular channel forms, and discontinuous cross-bedded and plane-bedded sandstone lenses are all typical of gravel-bedload stream deposits (e.g., Miall, 1977).

The channel facies merge laterally with flood-plain deposits consisting primarily of interbedded fine-grained sandstone, siltstone, and minor claystone in tabular, commonly normal-graded beds with sharp, undulating bases. Depositional structures in the overbank materials are partly to completely obliterated by bioturbation, but trough cross-bedding and ripple cross-lamination are locally preserved. Isolated channel fills of coarse-grained pebbly sandstone mark the probable courses of chute channels that were occupied during floods. Root traces and local stumps are lined with silica and light-colored clay and, with occasional burrows, reflect bioturbation in the flood-plain environment.

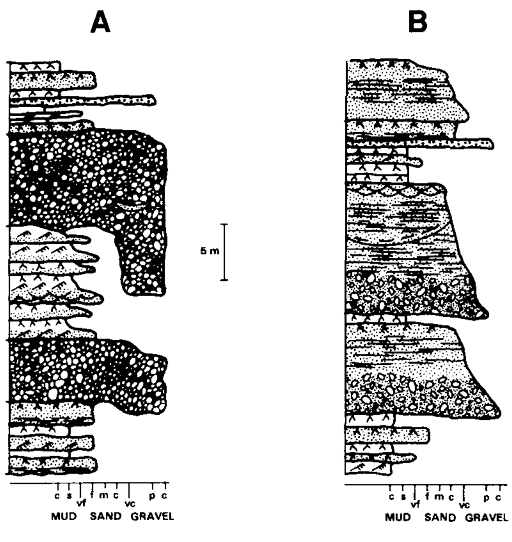



*Figure 7. Schematic representations of the two common facies assemblages seen along the depositional tract of the ancestral Deschutes River. A. Alternating sandy conglomerates and bioturbated graded sandstones and siltstones record channel and overbank facies associated with a channelized gravel-bedload stream. B. Some overbank sequences include graded-stratified hyperconcentrated-flow facies deposited across flood plains during large-volume, sediment-laden floods, probably related to eruption-induced debris flows that crossed the alluvial plains to the southwest and were diluted to hyperconcentrated flows by mixing with ancestral Deschutes River water.*

Numerous bioturbated or partly reworked pyroclastic-fall deposits occur as continuous layers of white pumice lapilli and ash that drape irregularities on depositional surfaces. These deposits are found only with overbank facies, reflecting the relatively stable surficial setting necessary for preservation.

Also occurring with overbank deposits or at vertical transitions from channel to overbank facies are hyperconcentrated-flow deposits (Figures 7b, 8). Hyperconcentrated flows represent a sediment transport condition that is intermediate between normal, dilute stream flows and viscous debris flows (Smith, 1986a; Smith and Lowe, in press). Sediment is deposited rapidly from high-concentration dispersions and sorted by limited tractive transport under waning-flow conditions. The resulting coarse sandstones and pebbly sandstones seen here range in thickness from 0.7 to 8.0 m and typically consist of a massive base that fines upward into a crudely bedded upper part (Figure 8). Scour surfaces occur between depositional units, but internal scours and cross-bedding are rare to absent. Pumice lapilli, if present, are typically concentrated near the top of the bed. The occurrence of hyperconcentrated-flow deposits with overbank facies (Figure 7b) reflects the high discharges and large volumes of the causative floods. The restriction of this facies to overbank environments results from its reworking where initially deposited in channel settings. Hyperconcentrated-flow deposits are thickest and most abundant within the ancestral Deschutes River deposits, probably representing the genesis of these flows by dilution of large debris flows that crossed the arc-adjacent alluvial plain (Stops 4 and 5) as they entered the channel of the larger stream.

The prominent columnar-jointed basalt near the top of the grade is the Seekseequa basalt member (Smith, 1986c). The lava flow is one of three basalts and one ignimbrite unit that filled and overflowed the ancestral Deschutes River channel (dotted course in Figure 4b). Lateral tracing of these units permits determination of the dimensions and course of the channel that was filled. The main channel at the time of eruption of the Seekseequa basalt was located 2 km to the west of here, was 10 m deep and 50 m wide, and flowed toward the north-northeast. At this location, the basalt rests on a thick hyperconcentrated-flow unit that formed the top of a terrace adjacent to the channel. Erosion along the top of the basalt and overlying conglomerate record the repositioning of the channel following the emplacement of the lava flow.

At the top of the illustrated section (Figure 6) near the gate is a pink ignimbrite, informally named the Jackson Buttes ignimbrite member (Smith, 1986c). The dispersal of moderately rounded to rounded pumice lapilli in a massive, crystal-rich, ashy matrix is the typical appearance of unwelded ignimbrites. Pink and orange colors are common and result from high-temperature oxidation of iron within glass and mineral grains during fumarolic activity following emplacement. Pumice lapilli in the Jackson Buttes ignimbrite are white and light-gray in color, reflecting compositional heterogeneity of the erupted magma ranging from rhyodacitic to rhyolitic (Smith, 1986c).

Despite the apparently uniform medium- to dark-gray color of most medium- to coarse-grained sandstones in this section, the composition of the sediments is quite variable. Sandstones associated with the conglomerates consist primarily of basalt and basaltic andesite lithic fragments with groundmass textures and crystals of plagioclase, olivine, and occasional clinopyroxene. These sands are, therefore, primarily composed of epiclastic fragments eroded from mafic lava flows, which are the dominant component

*Figure 8. Graded-stratified hyperconcentrated-flow deposit resting on light-colored, bioturbated overbank facies (~78- to 84-m interval shown on Figure 6). Note concentration of cobbles at the base of the unit and upward increase in definition of horizontal stratification as grain size decreases to medium-coarse sand.*

of the Deschutes Formation on Green Ridge located closer to the Cascade Range source area. The hyperconcentrated-flow deposits, on the other hand, consist almost entirely of vesicular glassy pyroclasts and free crystals of complexly zoned plagioclase, clinopyroxene, and orthopyroxene. This mineralogy is typical of many of the dacitic and rhyodacitic ignimbrites in the Deschutes Formation, many of which contain mostly dark-brown to black ash and pumice (e.g., Peninsula ignimbrite member at Stop 6). Hyperconcentrated flows, therefore, consist mostly of pyroclastic debris and probably occurred directly or indirectly in response to eruptions that generated large volumes of loose pyroclasts. The fluvial conglomerates and related sandstones, on the other hand, were not deposited as responses to volcanism and contain a greater percentage of epiclastic fragments.

### DIRECTIONS TO STOP 3

Return to Belmont Lane and turn right (south) on Mountain View Road, 0.5 mi beyond the Round Butte Dam gate. Follow Mountain View Drive for 6.25 mi to Stop 3 at a marked viewpoint over the Crooked River at The Cove Palisades State Park.

### GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 3

Mountain View Drive climbs onto the Round Butte shield volcano and then descends its south flank and traverses basalt flows in the upper Deschutes Formation erupted from both Cascade and intrabasinal sources. From near the south base of Round Butte are good views to the southeast of the western end of the Ochoco Mountains (Figure 1). The prominent mesas and small peaks are largely underlain by uplifted rhyolitic ignimbrites and lava flows of the John Day Formation (Robinson and Stensland, 1979). The westernmost of these topographic features, Juniper Butte, is a large rhyolite dome.

### STOP 3. THE COVE PALISADES STATE PARK: OVERVIEW OF THE DESCHUTES BASIN AND CENTRAL OREGON HIGH CASCADES

The Cove Palisades State Park marks the confluence of the Deschutes, Crooked, and Metolius Rivers, which have been impounded behind Round Butte Dam to form Lake Billy Chinook (Figures 1 and 2). Sediments, ignimbrites, and lava flows of the Deschutes Formation are well exposed in road cuts and in natural canyon-wall exposures. Pleistocene basalt flows also seen at Stop 2 form conspicuous, 150-m-high columnar-jointed basalt cliffs at The Island (Figure 9), which separates the Deschutes and Crooked Rivers. They are also exposed along the Crooked River upstream of the bridge as erosional remnants that rest against the Deschutes Formation along profoundly disconformable contacts.

Deschutes Formation outcrops at The Cove represent arc-adjacent alluvial plain facies interbedded with basalt flows and dacitic to rhyolitic ignimbrites. The ancestral Deschutes River was located to the east of the present canyons. About 200 m of Deschutes Formation crops out above the level of the lake, but the section represents only a relatively short time period between about 5.6 Ma and 5.3 Ma (Snee, personal communication, 1985; Smith, 1986c). This was a period of voluminous extrusions in the ancestral Cascade Range, which was located in the same general location as the modern peaks that are visible from this point. Rapid subsidence of the central Oregon High Cascade graben began at about 5.4 Ma (Smith and others, 1987). The eastern margin of the depression is marked by Green Ridge, a 700-m-high topographic escarpment whose forested crest and dip slope can be traced southward from a point in front of snow-capped Mount Jefferson to the forested cone of Black Butte (Figures 2 and 9). At least 1 to 2 km of structural relief was formed across the Green Ridge fault zone and terminated the transport of volcaniclastic debris from the Cascade axis to the Deschutes basin. This material accumulated instead within the intra-arc basin to form at least 2 km of lacustrine and fluvial sediments and tuffs that are locally exposed along the west base of Green Ridge, where they have been informally named the Camp Sherman beds (Figure 3) (Smith, 1986c). Basalt and basaltic andesite lavas were erupted from vents along the Green

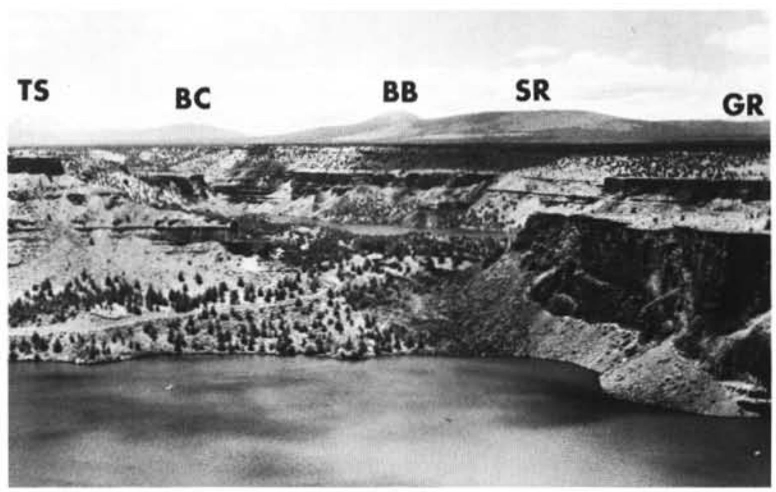



*Figure 9. Westward view from Stop 3 across The Cove Palisades State Park to the crest of the High Cascades. Crooked River arm of Lake Billy Chinook in foreground; Deschutes River arm in rear. Road in center of view passes between Deschutes Formation outcrops of The Ship (on the left) and early Pleistocene intracanyon basalt composing The Island (on the right). Other erosional remnants of the intracanyon lavas form dark, flat-topped outcrops above the Deschutes River. Prominent features along the skyline include the Three Sisters (TS), Black Crater (BC), Black Butte volcano (BB) at the south end of Green Ridge (GR), and Squawback Ridge (SR).*

Ridge fault zone and became the last volcanic units to flow eastward into the Deschutes basin. These lavas form the rimrock on the west side of The Cove and, on the east side, are intercalated with basalts erupted within the basin.

### DIRECTIONS TO STOP 4

Continue south on Mountain View Road for 0.7 mi to its intersection with an unnamed road leading into The Cove Palisades State Park. Turn right and proceed 6.8 mi across both the Crooked and Deschutes Rivers to Stop 4a. Parking is available on the east side of the road, just above the second switchback. Stop 4b is at the top of the highway grade an additional 1.1 mi to the west. These stops involve viewing of road cuts along the steep, winding road that climbs the west wall of the Deschutes Canyon. Considerable caution should be exercised in selecting a safe parking place, and a watchful eye for traffic is necessary while examining the outcrops.

### GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 4

A variety of Deschutes Formation lithologies are exposed along the highway within the state park. The quarry near the east entrance is developed in the Agency Plains basalt flow of the Tetherow Butte member. This is one of two lavas that flowed as far as 60 km from a vent complex at Tetherow Butte, 26 km to the south of here. The Tetherow Butte lavas are the most extensive of those erupted within the Deschutes basin during the same period as the principal collapse of the High Cascades. Two ignimbrites and a variety of sediments are exposed along the road that descends and follows along the Crooked River. A parking area at The Ship (Figure 9) between the Deschutes and Crooked Rivers is adjacent to outcrops of Deschutes Formation sediments and ignimbrites, including the prominent white Cove ignimbrite member that will be examined at Stop 4a.

### STOP 4. ARC-ADJACENT ALLUVIAL PLAIN FACIES OF THE DESCHUTES FORMATION: THE COVE PALISADES STATE PARK

Road cuts above the Deschutes River provide an opportunity to examine arc-adjacent alluvial plain facies of the Deschutes Formation. Two parts of the section will be examined.

#### Stop 4a

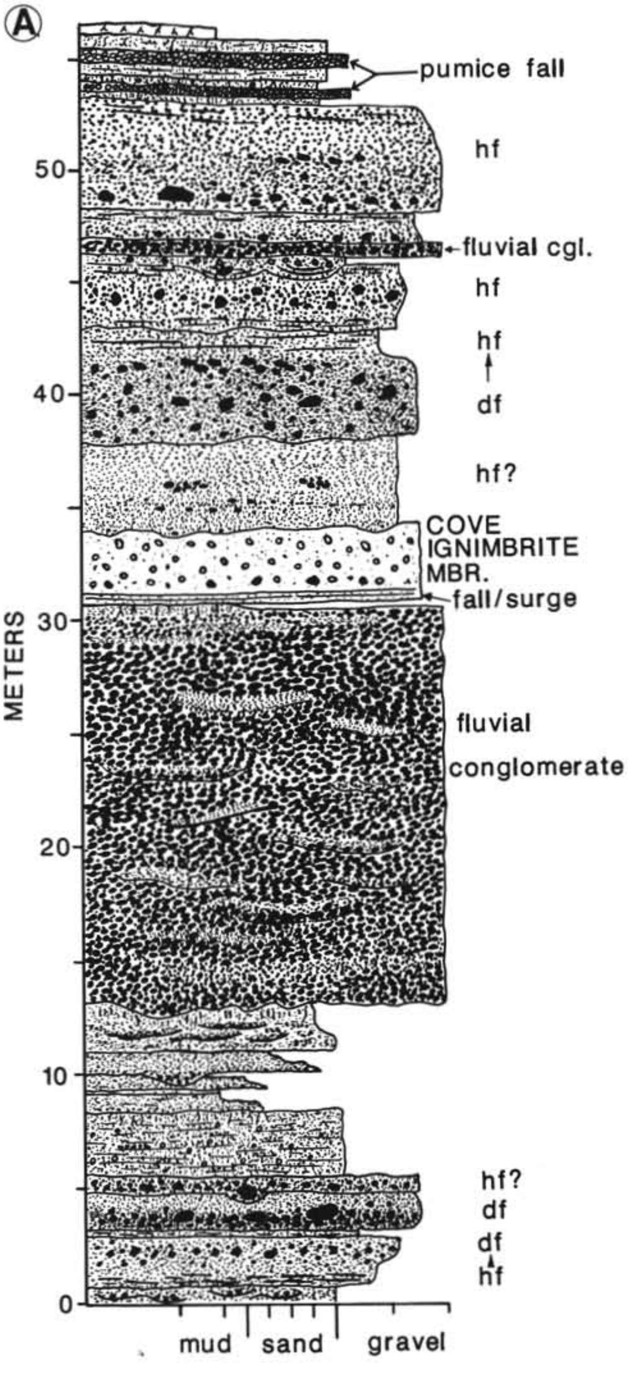
The section illustrated in Figure 10a for Stop 4a begins about 15 m below the second switchback and extends upward to a level about even with the prominent intracanyon basalt bench. Erosional remnants of the Jackson Buttes ignimbrite member can be seen enclosed in gravel just above the first switchback; therefore, the stratigraphic interval examined here is slightly higher than that seen at Stop 2.

Near the center of the section shown in Figure 10a and directly opposite the parking area is a fluvial conglomerate similar to conglomerates seen at Stop 2. This conglomerate, however, is restricted to a 15- to 20-m-deep and about 300-m-wide valley whose margins trend N. 40° E. to N. 70° E. through the park and record an east-flowing stream. This conglomerate contains only Cascade clasts and lacks the associated well-developed flood-plain deposits that characterize the ancestral Deschutes River deposits; the latter feature is probably a result of the restricted dimensions of the valley. The conglomerate records inter-eruption, normal fluvial sedimentation within a small valley incised into syneruption flood and debris-flow deposits. This is the stratigraphically highest such gravel known. Above this level, intervals of syneruption flood and debris-flow deposits are separated by erosion surfaces with little or no associated normal-streamflow gravel. The younger deposits accumulated only in response to volcanism-induced sediment loads and were not adequately accommodated by basin subsidence to permit aggradation by inter-eruption graded streams (Smith. 1987d, in press).

The section exposed below the conglomerate includes two volcanic debris-flow deposits (Figure 11). These flows are composed of Cascade material that originated 35 km to the west. The upper deposit is about 1.5 m thick and is a massive, inverse-to-normal-graded unit with clasts up to 0.75 m across supported in a matrix of sand and silt. Close examination of the fine-grained matrix shows the presence of small vesicles caused by air trapped in the viscous water-sediment mixture during transport; these are relatively common features of both volcanic and nonvolcanic debris-flow deposits and should not be taken as indication of the presence of a high-temperature vapor phase (Smith and Lowe, in press). The abundance of rounded clasts suggests that this debris flow bulked material from the streambed during transit (Scott, 1988; Smith and Lowe, in press). A thin sandstone separates this deposit from that of the lower debris flow. This deposit is about 1.8 m thick and contains more angular clasts reaching maximum dimensions of only 15 cm. The matrix of this unit is very sandy and lacks the abundant silt seen in the higher debris-flow deposit. The upper two-thirds of the bed has a typical massive, debris-flow texture but grades downward into a slightly better sorted, finer grained, and crudely stratified basal zone (Figure 11). Vertical variations of this type are the record of successive passage of genetically related hyperconcentrated and debris flows, the former generated from the latter by dilution through addition of stream water (Pierson and Scott, 1985; Smith, 1986a, 1987d; Scott, 1988; Smith and Lowe, in press). A hyperconcentrated-flow deposit at this stratigraphic position, 3.5 km down the paleoslope to the northeast, may record the complete dilution of this debris flow to hyperconcentrated flow. Mud-rich debris flows are less susceptible to dilution to hyperconcentrated flows than are those with granular matrices (Scott, 1988). This may be one factor that accounts for the lack of a hyperconcentrated-flow deposit beneath the higher debris-flow unit.

Above the conglomerate is the Cove ignimbrite member (Figure 10a) (Smith, 1986c), the most conspicuous pyroclastic-flow deposit at The Cove. The 3.2-m-thick white ignimbrite contains rhyodacitic pumice lapilli up to 8 cm in diameter and a variety of accidental or accessory lithic fragments up to 20 cm across that occur mostly near the base of the unit. The ashy matrix of the ignimbrite contains a great abundance of plagioclase crystals that were concentrated in the matrix as fine ash was elutriated from the fluidized flow during transport (Walker, 1971). About 70 cm of bedded pyroclastics occur beneath the ignimbrite. From bottom to top this unit includes (1) 50 cm of coarse ash, fine lapilli, and abundant accretionary lapilli; (2) 2 cm of pumice lapilli and angular lithic fragments up to 4 mm across; (3) about 15 cm of ash; and (4) a discontinuous, lenticular unit of plane-bedded and low-angle cross-bedded ash. The first three layers exhibit uniform mantle bedding typical of fall units; the fourth layer is interpreted as a ground-surge deposit generated by ingestion of ambient air at the head of the pyroclastic flow and better developed beneath the Cove ignimbrite at other localities. The variable textures of the fall layers beneath the ignimbrite reflect complexities of the eruption.

An erosion surface truncates the upper part of the tuff here and cuts down through all of it toward the north. Stratigraphic studies in this area show that at least 10 m of sediment deposited above the Cove ignimbrite member have also been removed here. A remnant of these scour-and-fill bedded, shallow braided-stream and sheetflood deposits capped by an oxidized massive sandstone paleosol crops out along the road about 15 m to the south (not shown on Figure 10a). The paleosol probably formed after the erosion surface developed, leaving high areas on the surface as relatively stable areas, while deposition was occurring along channels and valleys at lower elevations. Most of the arc-adjacent alluvial plain stratigraphy consists of depositional packages bounded by



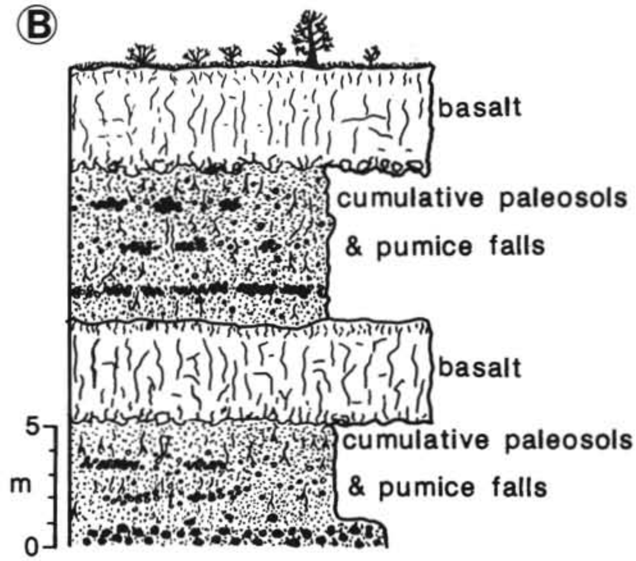




*Figure 10 (left and above). Graphic measured sections of the Deschutes Formation near the west entrance to The Cove Palisades State Park, Stop 4. A. Section along road at Stop 4a; designated parking area is at approximately the 20-m level. See text for discussion of critical features. hf = hyperconcentrated flow; df = debris flow. B. Section along road at top of the Deschutes arm grade at Stop 4b showing basalt flows intercalated with pedogenically modified sandstones and lapillistones typical of the upper part of the alluvial-plain section.*

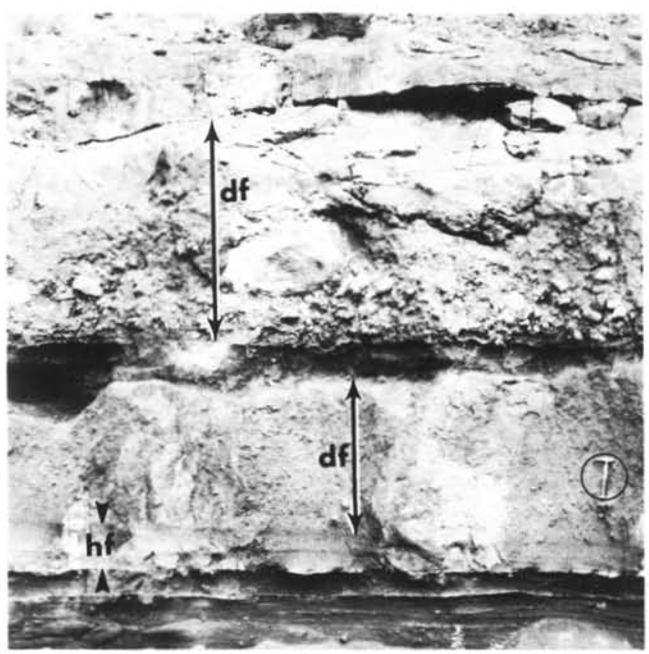



*Figure 11. View of debris-flow deposits (df) at 1- to 5-m interval of section shown in Figure 10a (Stop 4a). Note stratified hyperconcentrated-flow deposits (hf) underlying the lowest debris-flow deposit. See text for discussion.*

erosion surfaces; the complexity of the stratigraphy, therefore, is not easily evaluated in vertical sections but requires careful lateral tracing of volcanic marker units, erosion surfaces, and paleosols along the canyon walls.

The remainder of the section illustrated in Figure 10a is a sequence of poorly sorted, massive to crudely stratified conglomerates (Figure 12). None of these conglomerates is as well sorted or stratified as the normal fluvial conglomerates seen below the Cove ignimbrite or at Stop 2. Some beds have abundant fine-grained matrix and are probably debris-flow deposits. Most of these conglomerates, however, conspicuously lack sub-1-mm grains, are commonly normal graded and crudely stratified, and exhibit clast fabric that is relatively simple and nonrandom; these characteristics suggest deposition from hyperconcentrated flows (Smith, 1986a; Smith and Lowe, in press). Thin scour-and-fill bedded pebbly sandstones intervene between some of these units and represent deposition by shallow, flashy discharge braided streams. This part of the section is capped by 3.5 m of bioturbated, relatively thin-bedded sandstones and pumice-fall lapillistones recording diminished sedimentation rate and

*Figure 12. Poorly sorted debris-flow and hyperconcentrated-flow deposits overlying Cove ignimbrite member at Stop 4a.*

stability at this location, which correlates to a period of incision recorded by paleochannels to the north.

### Stop 4b

Stop 4b, at the top of the highway grade, provides exposures that are typical of the upper part of the arc-adjacent alluvial plain sequence throughout the basin (Figure 10b). The two basalt flows exposed here have been traced westward to Green Ridge, where they occur in the upper part of the section that postdates the initial development of relief across the Green Ridge fault zone (Conrey, 1985; Smith and others, 1987). Facies like those seen at Stop 4a and those that will be seen at Stop 6 are abruptly overlain across the entire alluvial plain by volcaniclastic materials of the type seen here in association with the basalt flows. Massive light-brown to orange sandstones (Figure 13) contain abundant rodent burrows, locally well-preserved root traces, and iron-oxide and clay rims around framework grains that account for the light color. These are paleosols developed cumulatively within thin depositional units of coarse-grained sand. Pumice-fall deposits, greatly disturbed by burrows (Figure 13), were emplaced with these sands, and pedogenic mixing of pumice lapilli and oxidized sand creates a "pseudo-ignimbrite" texture in the final deposit. These pedogenically modified sandstones and lapilli stones record the end of volcanism-induced aggradation in the basin and the onset of a period of landscape stability over most of the basin. Abundant pumice-fall beds, some as much as 2 m thick, record continued explosive volcanism in the Cascades, but no ignimbrites or flood and debris-flow sediments resulting from rapid stripping of pyroclastic debris from steep proximal slopes occur in this uppermost part of the section. These relationships are interpreted as the stratigraphic record of an intra-arc graben development. Subsequent arc-axis-erupted pyroclastic flows, lava flows, and products of eruption-related sedimentation events were trapped within the intra-arc basin, thereby starving the adjacent Deschutes basin from the sources of material that had accumulated there during the previous 2.5-m.y. period (Smith and others, 1987).

The high-alumina olivine basalts exposed at Stop 4a have diktytaxitic textures that are characteristic of most basalts within the Deschutes basin and within the Basin and Range province of southeastern Oregon (Hart and others, 1984). The texture is defined by the high density of small angular vesicles developed between unusually coarse groundmass plagioclase laths and results from rapid extrusion of relatively volatile-rich basalt that continues to vesiculate after a large degree of extratelluric crystallization is complete. Vesicle cylinders and pipe vesicles are common features of these flows. The cylinders are usually vertical and represent zones of diapiric rise of gas-rich melt (Goff, 1977) after the flow has come to rest. The pipe vesicles are restricted to the base of the flow and are generated by the rise of steam from a damp substrate. Pipe vesicles form as the flow is moving and are bent over in the direction of flow movement (Waters, 1960), providing measures of paleoslope orientation that, in this case, is inclined eastward.

## DIRECTIONS TO STOP 5

Retrace the route through The Cove Palisades State Park and follow signs to U.S. 97 and Madras. Proceed northward into Madras to the intersection with C Street; turn right (east). At about 0.6 mi, bear right on Grizzly Road. Continue for 1.8 mi and turn right (south) on the road leading to the county landfill. Park carefully on the shoulder at about 0.2 mi beyond the junction. The outcrops of interest at Stop 5 are about 20 m above the east side of the road.

## GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 5

Between The Cove Palisades State Park and U.S. 97, the route crosses remnants of Deschutes Formation sediments that were deposited following emplacement of the rimrock basalts at the park and before the formation of Round Butte. At least 50 m of sediment similar to facies seen at Stop 4b accumulated during a 1.4-m.y. period, but lateral planation by streams has removed all but a few meters of this section except near Round Butte. Road cuts leading into Madras consist largely of brown, oxidized, and pedogenically modified conglomeratic sandstones and lapilli stones typical of the inactive basin margin depositional setting of the Deschutes Formation (Figure 4a). Brightly colored rhyolite clasts, derived from the John Day Formation east of the Deschutes basin, are visible in these road cuts. Similar deposits are examined at Stop 5.

*Figure 13. Pedogenically disturbed sandstone and lapillistone at Stop 4b. Pumice-fall deposit to left of hammer grades into bioturbated pumiceous sandstone on right. Note rodent burrow at tip of hammer point and opalized root traces marked by arrows at bottom of photo.*

## STOP 5. INACTIVE BASIN MARGIN DEPOSITS OF THE DESCHUTES FORMATION, EAST OF MADRAS

Exposures here are typical of late Miocene sedimentation along the inactive northern and eastern margins of the Deschutes basin. Deschutes Formation lithologies extend only 2 km east from this point and onlap constructional and structural topographic highs composed of Oligocene John Day Formation. Composite exposures suggest that the section is less than 60 m thick in this area. The basalt flow capping the ridge to the east was erupted from a small shield volcano along the margin of the Ochoco Mountains, 15 km to the southeast of here, near the end of Deschutes Formation deposition.

The brown hues of the sandstones suggest pedogenic oxidation, as seen at previous stops. This interpretation is further supported by the paucity of preserved depositional structures, the abundance of insect and rodent burrows (Figure 14), and petrographic observations of oxidized clay coatings on framework grains (Smith, 1986c). John Day Formation ignimbrite clasts comprise the bulk of the sediment here (Figure 14), consistent with deposition by streams draining the Ochoco Mountains rather than the Cascades. Light-colored layers are distal ash- and pumice-fall tephras (Figure 14) derived from High Cascade volcanoes; Cascade pyroclastic debris also was reworked and admixed with epiclastic sediment to form the sandstones. Pedogenic disruption of the sediment, which is seen at all stratigraphic levels wherever the Ochoco- and Mutton Mountain-derived facies are exposed, reflects low sedimentation rates associated with these margins of the basin compared to the much higher and very episodic rates of deposition on the arc-adjacent alluvial plain to the west. The strong asymmetry of sediment volume and lack of basin-defining structures are clear indications of a primary volcanic, rather than subsidence-driven, mechanism for deposition and preservation of the Deschutes Formation.

*Figure 14. Light-colored pumice- and ash-fall deposit separating massive pedogenically modified sandstones and conglomerates characteristic of the inactive basin margin facies assemblage southeast of Madras at Stop 5. Arrows point to rodent burrows in and above pumice lapillistone. Insect burrows with meniscate fills can be found within the pyroclastic-fall bed and below it in the blocky textured, oxidized sandstone.*

Three different occurrences of paleosol sandstones are illustrated by Stops 4 and 5. Paleosol sandstones of the first type, at Stop 4a, are relatively thin (1 to 3 m) intervals of pedogenically disrupted sandstone that mark the tops of aggradational packages of syn-eruption flood and debris-flow facies, which are elsewhere bounded by erosion surfaces. Pedogenesis occurred on stable, relatively high-standing and well-drained parts of the landscape above incised inter-eruption channels. Paleosol sandstones of the second type, seen at Stop 4b, are thick (10 to 50 m) paleosols that are stratigraphically restricted to the upper part of the arc-adjacent alluvial plain section. These cumulic paleosols record an abrupt decrease in sedimentation rate resulting from structural isolation of the basin from its primary sediment source. Those of the third type, at Stop 5, represent the entire stratigraphic interval of the Deschutes Formation but are spatially restricted to the northern and eastern basin margins, where cumulic soil formation was a consequence of slow sediment accumulation in a depositionally inactive setting.

*This is the end of day one of the SEPM field trip. The guide for day two (Stops 6 and 7) begins at Ogden Wayside State Park located on U.S. 97, 18.5 mi south of Madras (8.4 mi north of Redmond).*

## DIRECTIONS TO STOP 6

Start at Ogden Wayside State Park located on the west side of U.S. 97 between Madras and Redmond, where the highway crosses the Crooked River. The overlook here features views of the 105 m-thick Pleistocene basalts that filled the ancestral Crooked River canyon; these are the same flows as seen at Stops 2, 3, and 4. Deschutes Formation basalts, tuffs, and sediments crop out on the north side of the canyon, east of the highway bridge.

Proceed 1.4 mi south on U.S. 97 and make a hard right turn on Wimp Way, followed by a left after 0.3 mi onto Ice Avenue. Ice Avenue ends after 2 mi at NW 43rd Street. Turn right (north) and continue about 1 mi to a "T" intersection and turn left. Stop 6 is reached by crossing the Crooked River Ranch residential and recreational development. Drive slowly and be observant for road signs. From the "T" intersection follow Chinook Drive for 2.45 mi and turn left (west) on Groundhog Road. Then make a succession of right turns onto Perch Road (0.3 mi), Steelhead Road (0.45 mi), and Rim Road Cutoff (0.4 mi). Continue for 1.2 mi on Rim Road Cutoff to the fire station and turn left on Rim Road. After 1.25 mi, turn right on Cinder Drive and continue on a winding course for 1.6 mi to Peninsula Road. Turn left on Peninsula Road and proceed 1.1 mi to North Meadow Drive. Follow North Meadow Drive for 0.55 mi and turn right on Scout Camp Trail. Continue approximately 0.7 mi to the end of the road on public land to the starting point for the hike to Stop 6. An unmarked but prominent trail descends northwestward into the Deschutes River canyon from the vicinity of the large juniper trees adjacent to the loop at the end of Scout Camp Trail. Figure 15 shows the location of specific features to be seen at this stop.

## GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 6

After leaving U.S. 97, the route along Wimp Road and Ice Avenue traverses the top of several basalt lava flows. The view southward from Ice Avenue includes Tetherow Butte, a series of low cinder and spatter cones that were the source of the extensive Agency Plains basalt described en route to Stops 1, 2, and 4. Forty-third Street skirts the edge of late Pleistocene (<700,000-year-old) basalts that were erupted near Newberry Volcano, 65 km to the south. These basalts, which have prominent pressure ridges and tumuli, entered the Deschutes River canyon to the northwest of here and flowed an additional 10 km to The Cove Palisades State Park, ending just upstream from Stop 4. Most of the route across Crooked River Ranch crosses Tetherow Butte member basalts, except for the rolling hills along Cinder Drive, which are

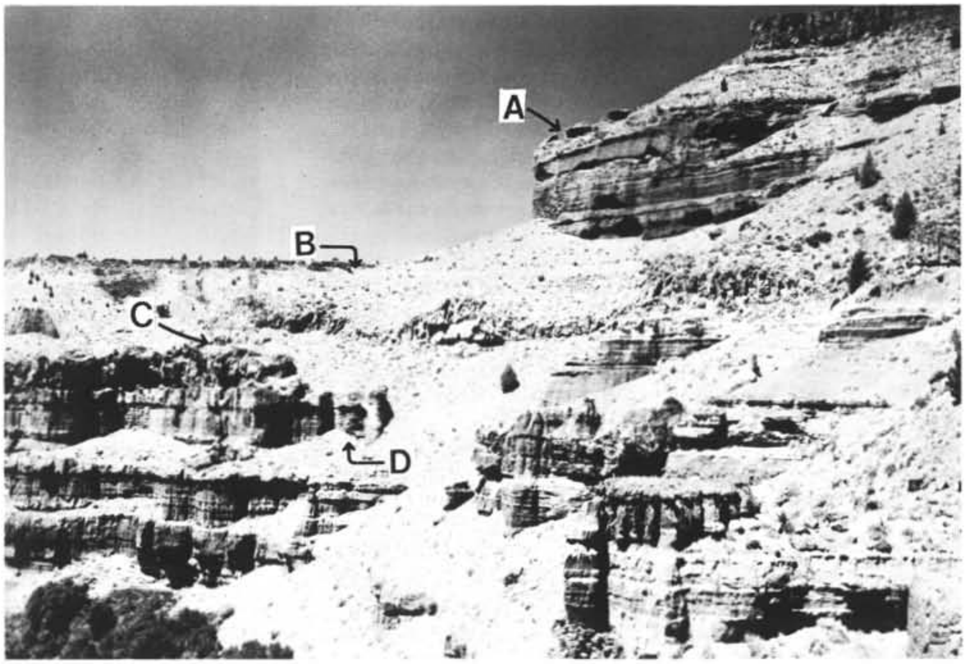



*Figure 15. View to the northwest of the east wall of the Deschutes River canyon, showing locations of Stops 6a, 6b, 6c, and 6d. Light-colored cliff former extending to the right from Stop 6c is the Steelhead Falls ignimbrite member. The height of exposure from the river at lower left to the canyon rim at upper right is 200 m.*

the eroded remnants of tuff cones, spatter ramparts, and small shield cones of the Steamboat Rock member of the Deschutes Formation, to be considered further at Stop 7.

### STOP 6. ARC-ADJACENT ALLUVIAL PLAIN FACIES AND FACIES GEOMETRIES, DESCHUTES CANYON AT SQUAW MOUTH

The spectacular exposures of the Deschutes Formation at the confluence of Squaw Creek and the Deschutes River illustrate the complete variety of facies characteristic of the arc-adjacent alluvial plain and the importance of recognizing erosion surfaces within the stratigraphy. The stratigraphic interval exposed here is roughly correlative to that seen at Stop 4. Highlights of the section are described for four locations that are marked on Figure 15.

**CAUTION:** The traverse requires a steep and somewhat strenuous descent and ascent of a 120-m-high portion of the canyon wall, mostly along deer trails. Three to four hours are required to complete observations at the four designated sites.

#### Stop 6a

The features of interest at this location are illustrated on Figure 16. The prominent Peninsula ignimbrite member (Smith, 1986c) rests on a pumiceous debris-flow deposit and is overlain by scour-and-fill bedded pumiceous sediments.

Where entirely preserved, the ignimbrite is about 9 m thick and consists of two parts. The basal 0.9 to 1.2 m is composed of pumice lapilli and bombs up to 15 cm across, lithic fragments up to 4 cm, clasts of the underlying debris-flow deposit, and virtually no ash. Breadcrusted exteriors of many bombs and magnetic-pole orientations measured by fluxgate magnetometer indicate that this bed was emplaced hot and is best described as "fines-depleted ignimbrite" (Walker, 1983). Beds such as this occur with several Deschutes Formation ignimbrites but are rarely continuous for more than a few hundred meters. They were probably the result of turbulence generated by the roughness of the irregular landscape that the pyroclastic flow passed over. The remaining ignimbrite has a more typical ashy matrix and consists of two flow units. The basal flow unit, about 1.2 m thick, is ungraded and contains lapilli to 4 cm across and lithic fragments to 3 cm. The overlying 7-m-thick flow unit shows distinct coarse-tail

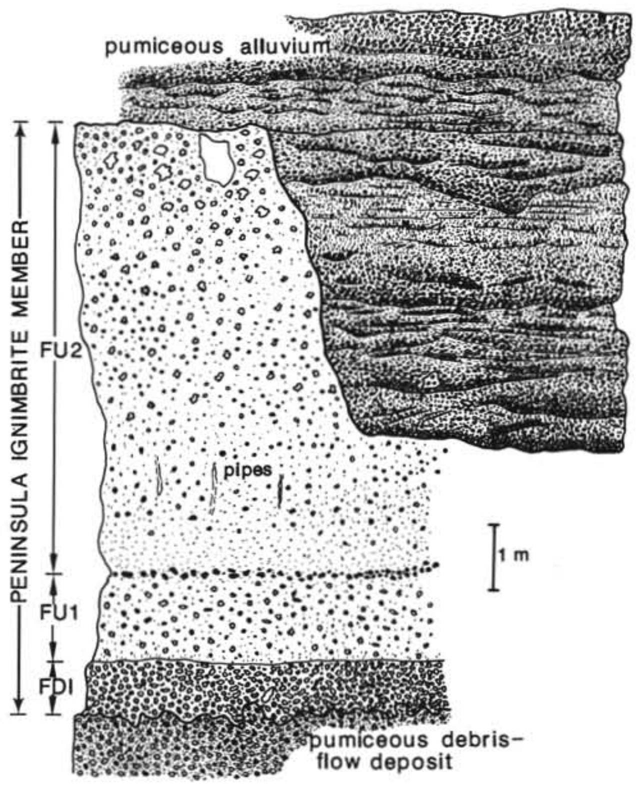



*Figure 16. Schematic representation of outcrop relationships at Stop 6a. The Peninsula ignimbrite member consists of a basal fines-depleted ignimbrite (FDI) and two normal ignimbrite flow units (FU1 and FU2). The ignimbrite overlies a pumiceous debris-flow deposit along a very irregular contact and is overlain by scour-and-fill bedded sediments largely derived from the ignimbrite. Open symbols represent pumice; closed symbols represent dense lithic fragments.*

normal grading of lithic fragments (from 8 cm up to 1 cm) and coarse-tail reverse grading of pumice (from 4 cm up to 40 cm); these features are common in the deposits of well-fluidized pyroclastic flows (Sparks and others, 1973). Fines-depleted pipes about 5 mm wide are locally present and represent elutriation of fine ash by rising gases following deposition. Pumice lapilli and bombs range in color from black to light-gray to white; some lapilli are banded. The white lapilli are rhyolitic in composition. Most black and light-gray lapilli are dacitic, but some of the large black bombs near the top of the ignimbrite are andesitic in composition (Smith, 1986c). Compositional heterogeneity is typical of most ignimbrites (see Hildreth, 1981, for a summary), requiring careful geochemical studies for adequate characterization of the ignimbrites for stratigraphic purposes.

About half of the approximately 100 ignimbrites known in the Deschutes Formation contain dark dacitic lapilli and ash, which accounts for the dark color of pyroclast-rich Deschutes Formation sediments that were erroneously related to basaltic provenance by some early workers. The coarse volcanic sandstones that overlie the Peninsula ignimbrite (Figure 16) are composed almost entirely of pyroclasts (lapilli and ash) derived from erosion of the unconsolidated ignimbrite. Epiclasts are also represented by clasts of tuff that were probably indurated by fumarolic alteration. These scour-and-fill bedded sediments occur in crude fining-upward sequences, 1.5 to 2.0 m thick, deposited by poorly confined, unsteady, shallow flows.

The Peninsula ignimbrite rests upon a well-indurated debris-flow deposit (Figure 16) along a very irregular contact produced by scour by the head of the pyroclastic flow. Only the upper 1-2 m of the debris-flow deposit, which totals at least 6 m in thickness, is accessible at this point. The deposit is essentially a lapilli tuff composed mostly of pumice lapilli and ash. The texture is similar to that of ignimbrites. Fluxgate magnetometer measurements of clast and matrix suggest, however, that the deposit lacks a thermal remanent magnetization. Several other observations also argue against a pyroclastic-flow origin: First, the matrix is very fine grained; very fine ash is generally elutriated from moving pyroclastic flows (compare hand samples of the debris-flow deposit and the Peninsula ignimbrite). Second, the matrix is locally vesicular, a feature caused by entrapment of air in a largely water-saturated matrix. Third, and less diagnostic, limb and trunk casts occur at the base of the deposit, and the impressions preserve bark, rather than charcoal, texture. Because most voluminous volcanic debris flows are generated by the mobilization of pyroclastic materials, they form pyroclastic deposits, and great care must be taken to distinguish them from texturally similar ignimbrites.

**Stop 6b**

A number of interesting features can be seen from a vantage point (Figure 15) on this spinelike ridge extending into the Deschutes Canyon. The principal features are described with respect to azimuth of view.

53°: The scale of channels in the alluvial plain sequence is dramatically illustrated by the ~15-m-high, vertical channel-wall margin preserved in the cliff-face exposure (Figure 17). Channels of this type are the typical architectural elements of the alluvial-plain sequence and can, in most cases, be correlated to paleosols developed in interchannel areas. Note that nearly all of the sedimentary facies visible on this cliff face appear to represent deposition by debris flows, hyperconcentrated flows, and other high-discharge flow processes. Fluvial gravels like those seen at Stops 2 and 3 are uncommon here and are rarely more than 1-2 m thick. Deposition of coarse flood and debris-flow transported sediment at this distance from source (~35 km) was probably in response to volcanic events. Inter-eruption periods are represented by channel incision and little to no net deposition (Smith, 1987d, in press). Because of the lack of well-developed cross-bedding or cobble imbrication within the alluvial-plain facies, channel orientations are the primary source of paleocurrent data; this channel wall strikes at about N. 20-30° E.

*Figure 17. Steep channel margin marked by arrows within flood and debris-flow-deposited strata described at Stop 6b. Large boulder above lower arrow is about 1.7 m in diameter. Note circled figure at lower left for scale.*

348°: This panoramic view down the Deschutes River canyon shows typical exposures of dark-colored sediments, dark-brown to black basalt and basaltic andesite flows (some with underlying, red "baked" zones), tan and pink ignimbrites, and white pumice-fall deposits comprising the arc-adjacent alluvial-plain sequence within the Deschutes Formation. High on the west wall of the canyon are alternating light-brown and white layers below the rimrock basalt that represent the paleosol and tephra-dominated top of the alluvial-plain section, as was also seen at Stop 4b. The prominent juniper-studded benches low on the canyon wall are the younger Pleistocene intracanyon basalt flows.

233°: This direction provides a view up Squaw Creek canyon, which follows close to the margin of the rimrock basalt flow. The lava is about 10-15 m thick on the north side of the canyon but thins to a margin on the south side.

108°: High on the east wall of the Deschutes Canyon is the margin of a channel that was filled by basalt; this channel trends N. 45° E. In the middle of the slope is a cliff-forming welded ignimbrite that will be examined at Stop 6c.

**Stop 6c**

The Steelhead Falls ignimbrite member is an important stratigraphic marker in the southern Deschutes basin (Smith, 1986c). At this locality, the unit grades from a 3- to 5-m-thick, gray, unwelded base, to a middle 8- to 10-m-thick crudely columnar jointed welded tuff that is tan or gray but weathers orange-brown, up to a slope-forming 5-m-thick unwelded top. In the northern part of the exposure, a rather abrupt transition from the unwelded base to the welded middle zone has been accentuated by weathering to produce a pseudo-bedding plane that does not extend southward. Length-to-width ratio for pumice lapilli increases from 3-6:1 for the unwelded base to 7-14:1 for the welded middle zone and reflects the compaction of lapilli to form fiamme in the welded tuff. No systematic grading of pumice or lithics is apparent in this unit, although a fine-grained inversely graded base is locally developed and consistent with implied high basal shear stresses during emplacement. Limited analyses suggest a dacitic composition for all of the pumice in this ignimbrite (Smith, 1986c). The ignimbrite rests on as much as 1 m of pumice-fall lapillistone.

At this location, the Steelhead Falls ignimbrite rests on a thin bioturbated sand that overlies basaltic flow breccia. This is the eroded margin of the lava flow, and this stratigraphic position is occupied by sediments to the south. The ignimbrite filled a southeast-northwest-trending trough composed of inset channel fills. Lower in the section there are a number of exposed channel margins that trend N. 70-80° W.

### Stop 6d

This location (Figures 15 and 18) provides additional opportunity for close scrutiny of the sedimentary facies comprising the arc-adjacent alluvial plain section. Most conspicuous here are scour-and-fill bedded units ranging in thickness from 1.5 to 10 m thick (Figure 19a). These deposits represent flashy, high-velocity, shallow flows that prohibited the production of bedforms that generate cross-bedding. Depths of scours are generally less than 25 cm and probably approximate the depths of the braided channels. The uppermost and thickest such deposit seen here is truncated by channels at the south end of the outcrop (Figure 18) but can be traced northward, roughly along depositional strike, for 1.5 km. This suggests that flows were very poorly confined and sheetlike in character. Vertically stacked scour-fill gravel lenses suggest that vertical accretion of sediment was more important than lateral accretion. The base of each sequence is often characterized by laminated fine-grained sands and silts with dispersed pumice lapilli (Figure 19b). These relatively quiet water deposits contain many leaf and stem impressions and insect burrows (Figure 19b) and tend to fill in irregularities on the underlying depositional surface. They may record overbank sedimentation during the initial stages of the depositional interval when flows were still confined to previously incised channels. Once the channels were filled, the subsequent poorly confined and strongly aggradational flows deposited the scour-and-fill bedded pebbly sands (Figure 19a) over the fine-grained sediments.

A >12-m-deep, vertical paleochannel margin truncates the thick sheetflood sequence at the south edge of the outcrop (Figure 18). A poorly indurated block of sheetflood sediment approximately 2.7 m long collapsed into this channel and can be seen at the base of the exposure. Most of the channel is filled with a generally upward fining conglomerate composed primarily of 0.5- to 5.0-cm-diameter grains with cobbles and boulders up to 1.2 m scattered throughout but largely concentrated at the base. There is virtually no component finer than 1 mm. The lower half is massive and grades into a crudely stratified upper part. Large clasts near the base are oriented with long axes parallel to the channel wall (and presumed transport direction), implying transport in a high-concentration fluid (Walker, 1975; Smith, 1986a). Low-density pumice and scoria increase in abundance upward. All of these features are consistent with deposition from a single hyperconcentrated flow. This deposit grades upward into about 2 m of bioturbated and partly oxidized sediment, which includes a remnant of an ash-fall bed and conspicuous inclined bedding. This material is interpreted as sediment that sloughed, washed, and blew into the channel over a lengthy interval of inactivity.

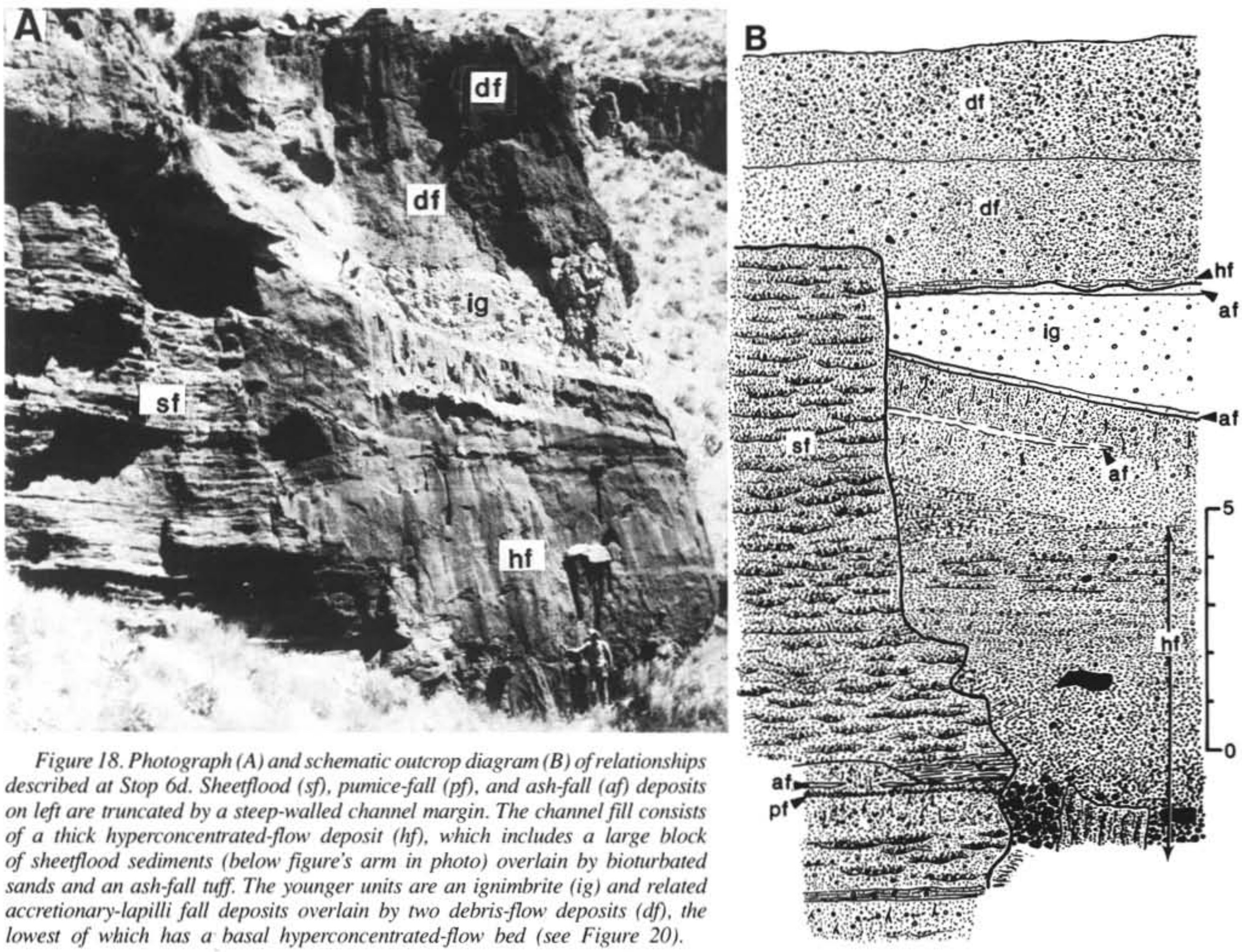



*Figure 18. Photograph (A) and schematic outcrop diagram (B) of relationships described at Stop 6d. Sheetflood (sf), pumice-fall (pf), and ash-fall (af) deposits on left are truncated by a steep-walled channel margin. The channel fill consists of a thick hyperconcentrated-flow deposit (hf), which includes a large block of sheetflood sediments (below figure's arm in photo) overlain by bioturbated sands and an ash-fall tuff. The younger units are an ignimbrite (ig) and related accretionary-lapilli fall deposits overlain by two debris-flow deposits (df), the lowest of which has a basal hyperconcentrated-flow bed (see Figure 20).*

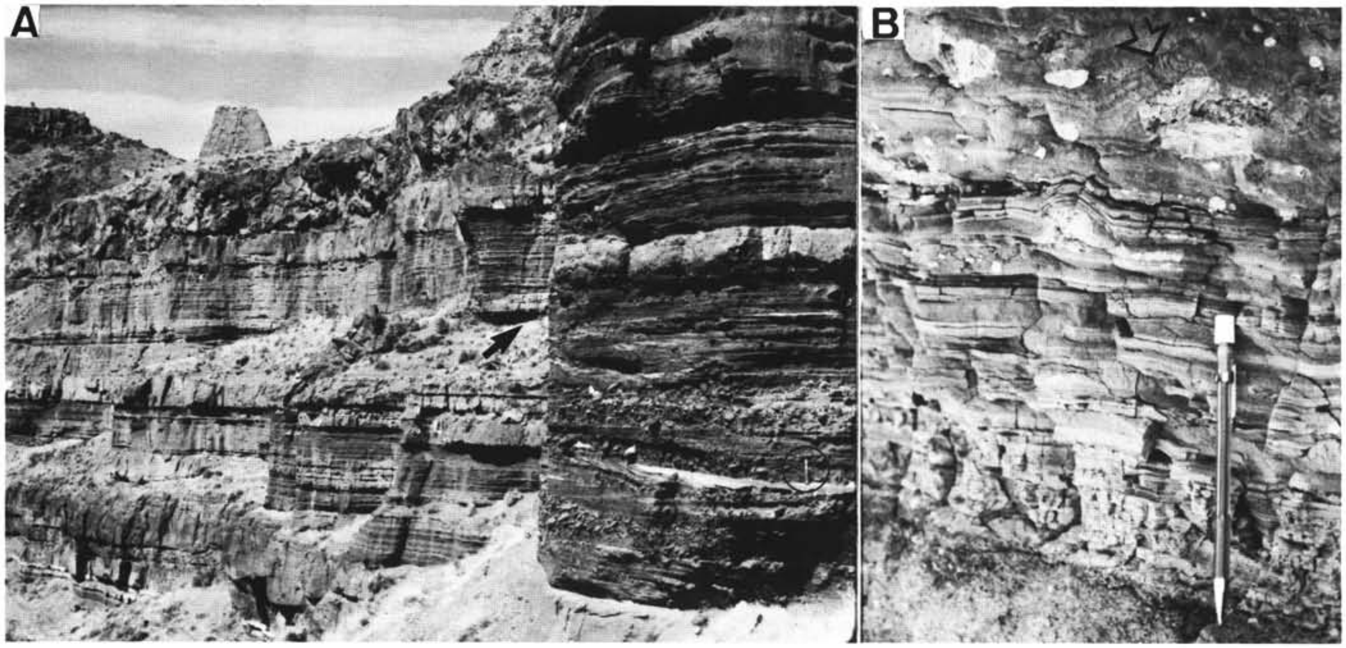



*Figure 19. Sheetflood deposits typical of the arc-adjacent alluvial plain setting as exposed at Stop 6d. A. Lateral continuity of sheetflood depositional packages, showing location of Stop 6d at arrow. Foreground outcrop, with hammer for scale, illustrates typical scour-and-fill sedimentary structures and lack of cross-bedding generated by migrating bedforms. B. Coarsening-upward sands and silts at base of sheetflood sequence. Pencil tip rests on paleosol developed on lower sheetflood deposits. Note draping of laminations over pumice lapilli, above and to left of pencil, and insect burrow with meniscate fill, marked by arrow.*

*Figure 20. Massive debris-flow deposit containing prominent dark rhyodacitic vitrophyre clasts with basal, compositionally similar, stratified hyperconcentrated-flow deposit (between arrows).*

The remaining minor paleotopography along the channel margin was filled by a fine-grained light-gray ignimbrite and associated fall deposits, which both underlie and overlie the ignimbrite (Figure 18). The falls are comprised of accretionary lapilli and fine-grained, angular ash shards. The ignimbrite also contains accretionary lapilli, along with pumice lapilli rarely exceeding 1 cm and ash. The fine-grained nature of the ignimbrite and the abundant accretionary lapilli suggest that these pyroclastics were the products of phreatomagmatic eruptions.

The youngest sediments seen at this locality are two debris-flow deposits that disconformably overlie both the ignimbrite and the sheetflood deposits adjacent to the channel fill (Figure 18). Each deposit is about 2.5 to 3.0 m thick and contains a conspicuous abundance of gray rhyodacitic vitrophyre clasts up to 3 cm long. The lower unit includes a 5- to 10-cm-thick horizontally bedded base composed of fragments of the same composition as the debris-flow deposit (Figure 20). The bedded base is inferred to represent the record of a hyperconcentrated flow that preceded the debris flow.

### DIRECTIONS TO STOP 7

Retrace the route along Scout Camp Trail and North Meadow Drive to Peninsula Road. Turn right (south) and proceed 0.7 mi to West Peninsula Road. Turn right and proceed 1.15 mi to Lower Ridge Road, turn right and continue another 0.35 mi to Canyon Drive. Turn right and continue for about 0.25 mi to Stop 7; park along the right shoulder.

### GEOLOGIC HIGHLIGHTS EN ROUTE TO STOP 7

West Peninsula Road skirts the flanks of an eroded basaltic tuff cone of the Steamboat Rock member of the Deschutes Formation (Figure 21) (Smith, 1986c). A thin spatter accumulation on the inner wall of the cone forms a conspicuous ledge to the east of West Peninsula Road near the junction with Lower Ridge Road. Lower Ridge Road cuts through the spatter and follows the moat between the old crater rim and a small shield cone, now capped by a water tower, within the crater. Canyon Drive descends a gully incised alongside a small lava flow that extended westward from the small shield through a breach in the crater wall.

### STOP 7. PYROCLASTIC SURGE DEPOSITS

Pyroclastic base-surge deposits are the product of rapidly moving, relatively dilute, and very turbulent mixtures of ash, lapilli,

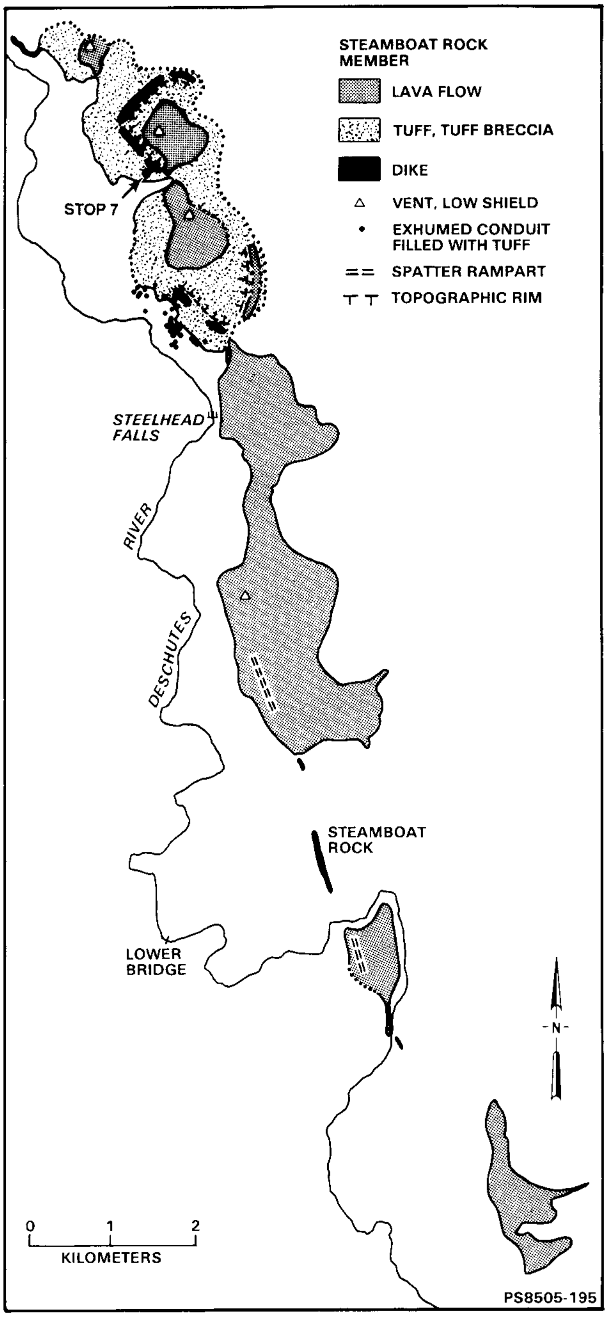



*Figure 21. Map of lavas, dikes, and pyroclastic rocks of the Steamboat Rock member of the Deschutes Formation, showing location of Stop 7. Lava flows were erupted from the southern end of the fissure system, whereas phreatomagmatic eruptions along the northern fissures generated tuff rings surrounding small, late-stage shield volcanoes.*

and gas (Fisher and Schmincke, 1984). Base surges move laterally from the basal part of eruptive plumes generated by phreatomagmatic eruptions and have been described in some detail by Fisher and Waters (1970). The resulting cross-bedded deposits are common in many volcanic terranes (e.g., Wohletz and Sheridan, 1979) and offer some challenge to sedimentologists, who might mistake them for fluvial or eolian facies.

The Steamboat Rock member of the Deschutes Formation includes the eruptive products related to a number of vents that formed along two en-echelon fissures that terminated near Stop 7 and extended at least 15 km to the south (Figure 21). The eruptions occurred at about 5.1 Ma (Snee, personal communication, 1985; Smith, 1986c) and represent one of several occurrences of intrabasinal volcanism during the period of High Cascade graben development. The line of the fissure vents correlates well with a steep Bouguer gravity anomaly gradient (Couch and others, 1982), suggesting that the magma rose along a deep-seated structure (Smith, 1986c). Relatively quiet Hawaiian-type eruptions along the southern part of the fissure system constructed low shield cones and spatter ramparts flanked by a thin lava flow. Magma rising along the northern part of the fissure encountered ground water, initiating phreatomagmatic explosions. Exposures of conduit structures (Figure 21) and identification of accessory-erupted clasts indicate that these explosions originated at a depth of about 250 m below the contemporary ground surface. Initial outbursts generated a basal explosion breccia, which is as much as 3 m thick but is discontinuous and no more than 0.5 m thick where exposed near the west end of exposures at this stop. Succeeding base surges produced 40 m of cross-bedded deposits at this site (Figure 22), spread from a vent centered beneath the water tower 0.5 km to the northeast.

Compared to phreatomagmatic deposits described in the literature (Fisher and Waters, 1970; Wohletz and Sheridan, 1983), those of the Steamboat Rock member represent relatively low water-to-magma-ratio explosions. Although containing a considerable volume of fine-grained, poorly vesicular, sideromelane ash, the deposits contain abundant cinder that must have formed principally by magmatic vesiculation. Other features of relatively wet eruptions, including accretionary lapilli, bomb sags, soft-sediment deformation, and oversteepened cross-beds, are absent here.

These outcrops provide an oblique section through the low crater rim, with tuffs at low elevations toward the west end of the outcrops being inclined westward away from the vent and tuffs at higher elevations to the east dipping eastward into the crater. The surge-deposited tuff and lapilli tuff are characterized by irregular pinch-and-swell structures and cross-beds that generally change westward from broad undulating trough forms to steeper trough and tabular cross-beds with preservation of both stoss- and lee-side laminae in some cases (sandwave facies of Wohletz and Sheridan, 1979) (Figure 22). These deposits also coarsen to the east. Continuous thin beds of coarse ash or cinder that drape surge bedform shapes are interpreted as fallout deposits.

The Steamboat Rock eruptions became drier with time, and basaltic tuff is overlain in many places with as much as 5 m of cinder and bombs. Outcrops of these late-stage materials are sparse at this site, but ribbon and fusiform bombs occur as float on the hillside. Fire fountains then developed within the crater to the east, veneering the inner crater wall with agglutinated spatter (capping the ridge above this locality), constructed the small shield cone beneath the water tower, and fed the lava flow that terminated on the other side of Canyon Drive. All juvenile products of the Steamboat Rock eruption are glassy, sparsely phyric transitional basalt/basaltic andesite (53.5 percent $SiO_2$) containing phenocrysts of augite and plagioclase. Coarser grained porphyritic basalts are prominent accessory constituents of the hydroclastic and fire-fountain deposits. They are derived from Deschutes Formation lavas about 250 m lower in the section.

Steamboat Rock member hydroclastic tuffs and lapilli tuffs may be distinguished from most similar-appearing fluvial facies by the absence of channel or scour structures and the preservation of stoss-side laminations in cross-beds (Figure 22), which are not commonly found in fluvial deposits. These hydroclastics are relatively thick near vents (up to 100 m) but do not extend more than 1 km from source. Distribution, therefore, is another helpful criterion for recognizing the primary volcanic origin of these

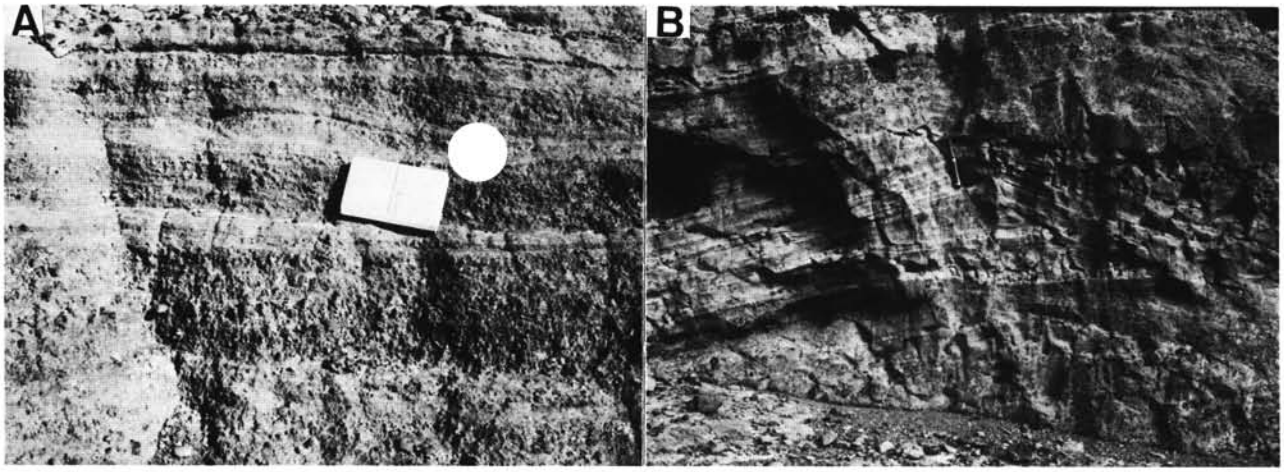


*Figure 22. Depositional structures in tuffs of the Steamboat Rock member at Stop 7. A. Plane-bedded fall unit, below notebook, and cross-bedded surge deposits behind and above notebook; flow from right to left. Note sigmoidal shape of stoss-side laminations and low-angle, tabular form of lee-side laminations in preserved sand wave immediately above notebook. B. Nearly symmetrical sand-wave cross-bedding; flow from right to left.*

volcaniclastic deposits. Although the sorting and abundance of coarse clasts would preclude confusing Steamboat Rock member tuffs with eolian deposits, some base surge deposits are much finer grained and can be more difficult to distinguish (Smith and Katzman, 1990).

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# DOGAMI publishes Index of Industrial Minerals Forum proceedings

**Index to Proceedings of the Forum on the Geology of Industrial Minerals, First (1965) through Twenty-Fifth (1989)**, compiled by Robert L. Bates. DOGAMI Special Paper 24, 43 p., $6.

The Forum on the Geology of Industrial Minerals was founded in 1965 and has met every year since then. Organizations in 22 different locations in Canada and the U.S. have acted as hosts during the first 25 years. After each meeting, the papers presented at the Forum are published by the host organization. Thus earlier this year, the Oregon Department of Geology and Mineral Industries (DOGAMI) released its Special Paper 23, the proceedings of the 25th Forum held in Portland in 1989.

Because of this method of publication, it is sometimes difficult to retrieve information contained in the published proceedings. The new publication now makes that information accessible with the help of an index.

The report, which was funded in part by the Society of Economic Geologists Foundation, Inc., brings together information on all the publications of the Forum's first quarter-century. The first section consists of the titles, citations, and contents of each volume of proceedings. Then comes a subject index, followed by an author index. Each entry of these indexes is keyed to the appropriate volume of proceedings, so the reader may find the title and full citation of a desired paper by referring to the first section. At the close of the report is an address list of the agencies that have acted as Forum hosts. □

# BLM appoints new managers

The U.S. Bureau of Land Management (BLM) has two new leaders in the Northwest: Robert D. Rheiner, Jr., was named associate state director for Oregon/Washington, and Michael T. Green will be the new District Manager for the agency's Burns District in Oregon.

Rheiner, a forester and veteran manager with BLM is currently the manager of BLM's Bakersfield District in California. He succeeds Paul M. Vetterick, who retired November 1, 1990. In 25 years of service with BLM, Rheiner has worked not only in California but also in Colorado, Idaho, and Washington, D.C.

Green is a 20-year veteran of BLM with a degree in wildlife management and working experience in Idaho, Alaska, and, most recently, Washington, D.C., where he worked on the budget staff of BLM's headquarters. □

# MINERAL EXPLORATION ACTIVITY

### MAJOR MINERAL-EXPLORATION ACTIVITY

| Date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| April 1983 | Susanville Kappes Cassiday and Associates | Tps. 9, 10 S. Rs. 32, 33 E. Grant County | Gold | Expl |
| May 1988 | Quartz Mountain Wavecrest Resources, Inc. | T. 37 S. R. 16 E. Lake County | Gold | Expl |
| September 1988 | Angel Camp Wavecrest Resources, Inc. | T. 37 S. R. 16 E. Lake County | Gold | Expl |
| September 1988 | Glass Butte Galactic Services, Inc. | Tps. 23, 24 S. R. 23 E. Lake County | Gold | Expl |
| September 1988 | Grassy Mountain Atlas Precious Metals, Inc. | T. 22 S. R. 44 E. Malheur County | Gold | Expl, com |
| September 1988 | Kerby Malheur Mining | T. 15 S. R. 45 E. Malheur County | Gold | Expl, com |
| September 1988 | Jessie Page Chevron Resources Company | T. 25 S. R. 43 E. Malheur County | Gold | Expl |
| October 1988 | Bear Creek Freeport McMoRan Gold Company | Tps. 18, 19 S. R. 18 E. Crook County | Gold | Expl |
| December 1988 | Harper Basin American Copper and Nickel Co. | T. 21 S. R. 42 E. Malheur County | Gold | Expl |
| May 1989 | Hope Butte Chevron Resources Company | T. 17 S. R. 43 E. Malheur County | Gold | Expl, com |
| September 1989 | East Ridge Malheur Mining | T. 15 S. R. 45 E. Malheur County | Gold | App |
| June 1990 | Racey Billiton Minerals USA | T. 13 S. R. 41 E. Malheur County | Gold | Expl |
| June 1990 | Grouse Mountain Bond Gold Exploration, Inc. | T. 23 S. Rs. 1, 2 E. Lane County | Gold | Expl |
| June 1990 | Freeze Western Mining Corporation | T. 23 S. R. 42 E. Malheur County | Gold | Expl |
| August 1990 | Lava Project Battle Mountain Exploration | T. 29 S. R. 45 E. Malheur County | Gold | Expl |
| September 1990 | Bourne Simplot Resources, Inc. | T. 8 S. R. 37 E. Baker County | Gold | App |
| September 1990 | Baboon Creek Chemstar Lime, Inc. | T. 19 S. R. 38 E. Baker County | Lime-stone | App |
| September 1990 | Prairie Diggings Western Gold Explora-tion and Mining Co. | T. 13 S. R. 32 E. Grant County | Gold | App |
| September 1990 | Pine Creek Battle Mountain Exploration | T. 20 S. R. 34 E. Harney County | Gold | Expl |
| September 1990 | Calavera NERCO Exploration Company | T. 21 S. R. 45 E. Malheur County | Gold | Expl |
| September 1990 | Cow Valley Butte Cambiex USA, Inc. | T. 14 S. R. 40 E. Malheur County | Gold | Expl |
| September 1990 | Mahogany Project Chevron Resources Company | T. 26 S. R. 46 E. Malheur County | Gold | App |
| October 1990 | Katey Claims Asarco, Inc. | Tps. 24-25 S. Rs. 44-46 E. Malheur County | Gold | Expl |
| October 1990 | Snake Flat Atlas Precious Metals, Inc. | T. 22 S. R. 44 E. Malheur County | Gold | App |
| October 1990 | Stockade Mountain BHP-Utah International | T. 26 S. Rs. 38, 39 E. Malheur County | Gold | Expl |
| October 1990 | Goldfinger Site Noranda Exploration | T. 25 S. R. 45 E. Malheur County | Gold | Expl |
| October 1990 | Buck Gulch Teague Mineral Products | T. 23 S. R. 46 E. Malheur County | Ben-tonite | Expl |
| November 1990 | Sand Hollow Noranda Exploration | T. 24 S. R. 43 E. Malheur County | Gold | Expl |
| November 1990 | South Star Claims Carlin Gold Com-pany, Inc. | T. 25 S. R. 39 E. Malheur County | Gold, silver | App |
| November 1990 | Stockade Project Phelps Dodge Mining Company | Tps. 25, 26 S. R. 38 E. Malheur County | Gold | App |
| November 1990 | Bornite Project Plexus Resources Corporation | T. 8 S. R. 3 E. Marion County | Copper | App |
| November 1990 | Martha Property Cambiex USA, Inc. | T. 33 S. R. 5 W. Josephine County | Gold | App |

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

**Status changes**

During October and November, ten new applications were received. Bond Gold completed exploration and reclamation of its Noonday Ridge project, and the file has been closed. Reclamation on numerous sites was totally or partially completed prior to the onset of winter weather. Permits will not be closed, and some bond money will be held until disturbed areas are successfully revegetated.

Questions or comments about exploration activities in Oregon should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office, 1534 SE Queen Avenue, Albany OR 97321, telephone (503) 967-2039. □

# MLR office adds staff member

Douglas A. Galipeau has joined the Mined Land Reclamation Program (MLR) of the Oregon Department of Geology and Mineral Industries in Albany.

A mining engineer by his professional training, Galipeau comes to MLR from a position as cavern engineer for an underground salt mine project of Boeing Petroleum Services in Louisiana. During the past 15 years, he also has had working experience in surface coal mining in Wyoming and in well drilling, both for oil exploration and water wells.

As Environmental Specialist, Galipeau is a welcome addition to the MLR staff that administers the continually growing program of regulating mining exploration and development in Oregon. □

# Significant Oregon earthquakes in 1990

Since 1970, the University of Washington has operated a seismic network in Oregon capable of recording relatively small earthquakes. In 1990, the network was expanded with four new stations near Corvallis, Eugene, and Roseburg. In addition, Oregon State University began operating a high-gain, broadband seismic station in Corvallis in 1990. Also in 1990, the University of Oregon received funding to install a network of six broadband instruments throughout the state. These improvements in instrumentation promise to teach us a great deal about Oregon seismicity in the years to come.

As a service to the readers of *Oregon Geology*, the Oregon Department of Geology and Mineral Industries (DOGAMI) will, in the future, publish reports of significant earthquakes in Oregon as they occur. A complete catalog of Oregon earthquakes and quarterly updates published by the University of Washington are available in the DOGAMI library.

Seismic activity in Oregon is low in comparison to neighboring states, but three significant earthquakes or groups of earthquakes were recorded in Western Oregon this year.

### HEMBRE RIDGE EARTHQUAKE

At 9:56 p.m. on April 5, 1990, a magnitude (mc) 3.2 earthquake occurred about 22 km east of Tillamook. The earthquake was located at a depth of 43.5 km beneath Hembre Ridge in the Coast Range. The focal mechanisms calculated for this event are poorly constrained and preliminary. One solution suggests SE thrust motion on a fault which strikes 040° (NE) and dips 8° NW. The other solution suggests reverse motion on a fault that strikes 040° (NE) and dips 82° SE. This event was felt by several people in the Tillamook area and was reported to local emergency management agencies.

### WOODBURN EARTHQUAKEES

A swarm of earthquakes occurred beneath Woodburn, Oregon, between August 14 and August 23, 1990. The smallest event recorded had a magnitude (mc) of 1.4, the largest had a magnitude (mc) of 2.5. The earthquakes occurred at a depth of 29 km and were not reported as felt. Nabelek and others (1990) report that seismic waveforms recorded by the Oregon State University broadband seismic station were remarkably similar, suggesting identical locations and mechanisms. The authors estimate a focal mechanism of right-lateral strike-slip motion with a small thrust component on a fault plane striking 340° (NNW) and dipping steeply east. They suggest that the earthquake swarm was located near, and was possibly associated with, the Mount Angel Fault that cuts Columbia River basalt and overlying alluvial deposits.

### MOUNT HOOD EARTHQUAKE

An earthquake was felt by residents of Government Camp and Timberline Lodge at Mount Hood on October 18, 1990. The epicenter was located at Timberline Lodge, and the earthquake occurred at a depth of 6 km with a magnitude (mc) of 3.5. The main event was accompanied by two small foreshocks and several dozen aftershocks. The focal mechanism was estimated as either left-lateral slip on a plane striking 030° (NNE) and dipping 48° NW or right-lateral slip on a plane striking 330° (NNW) and dipping 60° NE. Both focal mechanisms have a component of normal dip slip.

This earthquake was very similar to earlier events at Mount Hood in 1989, 1982, and 1974.

### ACKNOWLEDGMENTS

Information for this report was cheerfully provided by Craig Weaver and Tom Yelin of the U.S. Geological Survey office at the University of Washington, Steve Malone and Chris Jonientz-Trisler of the University of Washington Geophysics Program, John Nabelek of the Oregon State University College of Oceanography, and Gene Humphreys of the University of Oregon Department of Geosciences.

### REFERENCE CITED

Nabelek, J., Werner, K., Yeats, R.S., and Malone, S., 1990, The August 1990 Woodburn, Oregon, earthquake sequence: Constraints from broadband regional recording and geological implications [abs.]: EOS, v. 71, no. 41, p. 1145. □

# AEG to host international symposium

The 15th International Geochemical Exploration Symposium of the Association of Exploration Geochemists (AEG) will be held April 29 to May 1, 1991, at Bally's Casino Resort in Reno, Nevada.

The Symposium's technical sessions will discuss geochemistry of gold and platinum deposits, integrated geophysical and geochemical exploration, and new analytical techniques. Poster sessions will be held concurrently. Fourteen field trips, three short courses, and two workshops will be divided between pre- and post-meeting times, and 150 industry vendors, consultants, and professional organizations will present displays and information stands.

For more information regarding program, registration, and accommodations, phone Mario Desilets at (702) 784-6691 or Erik Rorem at (702) 359-9330 or write to: 15th International Geochemical Exploration Symposium, P.O. Box 9126, Reno, NV 89507. □

# NWMA elects officers and trustees

The Northwest Mining Association (NWMA) elected new officers and trustees for the year 1991 at its 96th annual convention in Spokane last December.

The following officers were elected: President, David A. Holmes of Behre, Dolbear and Company, Inc.; First Vice President, Marshall A. Koval of Golder Associates; Second Vice President, John M. Willson of Pegasus Gold; Vice President, Karl W. Mote of the Northwest Mining Association; Secretary, John L. Neff of Nayes, Phillabaum and Harlow; and Treasurer, David M. Menard.

As trustees, the following were elected: Brian R. Hanson of Holland and Hart; Rod Higgins of Coeur d'Alene Mines Corporation; Keith R. Hulley of USMX, Inc.; John D. Marrington of Dynatec Mining Corporation; Leigh A. Readdy of Geological and Exploration Associates; Michael B. Richings of Atlas Precious Metals, Inc.; Linda E. Thorstad of Interaction Resources, Ltd.; and Christopher L. Widrig of Dupont Company.

—*NWMA news release*

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# OREGON GEOLOGY

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VOLUME 53, NUMBER 2 MARCH 1991

IN THIS ISSUE:
Jurassic flora from Hells Canyon
and
Prehistoric buried forests of Mount Hood

# OREGON GEOLOGY

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

## Cover photo

Evidence of forests buried in three major eruptive episodes of Mount Hood during the last 2,000 years is discussed in the article beginning on page 34. In photo, Author Ken Cameron's children are shown on a cedar stump in the Lost Creek Picnic area at Old Maid Flat near Mount Hood. Stump was once a tree that was buried by mudflows about 1780 A.D., during the most recent major eruptive episode of the volcano. Upper portion of the dead tree was apparently cut by early settlers for shake bolts; remaining trunk reaches about 5 ft farther below current ground level (visible root system in foreground is from other trees nearby).

# OIL AND GAS NEWS

### Mist Natural Gas Storage Project activity

Northwest Natural Gas Company drilled two injection-withdrawal service wells at the Mist Natural Gas Storage Project. The IW 33ac-3, located in sec. 3, T. 6 N., R. 5 W., was drilled in the Flora Pool to a total depth of 2,897 ft. The IW 32c-10, located in sec. 10, T. 6 N., R. 5 W., was drilled in the Bruer Pool to a total depth of 2,749 feet. Injection-withdrawal wells are used to add gas to and remove gas from the storage reservoir. There are now seven injection-withdrawal wells at the gas storage project; three in the Flora Pool and four in the Bruer Pool. The Bruer and Flora Pools have a combined capacity for the storage of 10 billion cubic feet of gas. This allows for cycling the reservoirs between approximately 400 psi to 1,000 psi and will provide for an annual delivery of one million therms per day for 100 days.

### Washington County wildcat drilled

Oregon Natural Gas Development Corporation drilled a wildcat well near Gaston in Washington County during January. The Van Dyke 32-26, located in sec. 26, T. 15 S., R. 4 W., was drilled to a total depth of 3,432 ft and was plugged and abandoned.

### Oil, gas, and geothermal permit legislation proposed

During the 1991 legislative session, the Oregon Department of Geology and Mineral Industries (DOGAMI) intends to file a bill in the 1991 legislature that would authorize the agency to require a fee not to exceed $250 when an application is made for a permit to drill an oil, gas, or geothermal well, or for a renewal of these permits. Current fees are $100 for an application for a permit to drill an oil, gas, or geothermal well and no fee for a permit renewal. The bill provides for DOGAMI to charge a fee not to exceed $500 annually for active permits issued by the agency. No annual fee for active permits is currently charged by the agency. The bill also provides that a geothermal permit will remain valid for one year from the date it is issued or renewed. Currently a geothermal permit remains valid for six months. For further information contact Dennis Olmstead or Dan Wermiel at DOGAMI's Portland office. □

# Earthquake workshop announced

The Oregon Department of Geology and Mineral Industries (DOGAMI) and Oregon State University (OSU) are sponsoring a **Workshop on Oregon Earthquake Source Zones** held March 18 in Room 110, Wilkinson Hall, on the OSU campus in Corvallis.

In morning presentations and an afternoon poster session and panel discussion the sponsors intend to provide an informal environment for scientists to discuss magnitudes, locations, and frequency of earthquakes in Oregon.

For more information, contact George R. Priest at the DOGAMI Portland office or Robert S. Yeats at the OSU Department of Geosciences, Corvallis, OR 97331, phone (503) 747-1226. □

# DOGAMI to raise 1982 prices

For the first time since 1982, the Oregon Department of Geology and Mineral Industries (DOGAMI) finds it unavoidable to raise the prices of its publications to keep up with rising costs all around.

The last two pages of this issue show the new prices effective March 1, 1991, for most of the publications and the subscription to *Oregon Geology*. Information on open-file reports and other publications for sale is sent upon request. □

# A new Jurassic flora from the Wallowa terrane in Hells Canyon, Oregon and Idaho

*by Sidney R. Ash, Department of Geology, Weber State University, Ogden, Utah 84408-2507*

## ABSTRACT

The flora that was recently discovered in the Wallowa terrane in the Hells Canyon area, Oregon and Idaho, is helping geologists more clearly understand the geologic history of the terrane and the region. The new flora occurs in the Coon Hollow Formation in the Wallowa Terrane in association with marine fossils of Middle Jurassic age. It includes about 15 species, all of which are now extinct, and contains horsetails, lycopods, ferns, ginkgoes, and conifers. The fossils indicate that the lower part of the Coon Hollow Formation was deposited under a humid, warm to hot climate with well-developed seasons.

## INTRODUCTION

A flora that was recently discovered in Hells Canyon in northeastern Oregon and adjacent areas in Idaho (Figure 1) is helping clarify the early geologic history of the area. This flora occurs in one of the many masses of rock, called suspect terranes, that apparently underlie the whole state of Oregon and a large part of western North America (Silberling and others, 1987). These terranes are suspected to have been formed elsewhere and later added (accreted) to the western edge of the North American craton by plate movement at various times during the Paleozoic and Mesozoic (Jones and others, 1977). In fact it now appears, after two decades of intensive study, that most of the western Cordilleran region, that is the region west of the Rocky Mountains and the Colorado Plateau, is a "vast mosaic or collage" of suspect terranes (Coney and others, 1980).

The rocks that make up the terranes are generally poorly exposed, strongly deformed, and relatively nonfossiliferous. Consequently, there is disagreement about many aspects of their geologic history and the environments of deposition in which they formed. Because the new flora has the potential of providing new data about one of the Oregon terranes, it is now being studied in detail. A summary of the preliminary findings on the flora is presented here together with a discussion of its paleoclimatic implications and comments about its relationships to other Mesozoic floras. Two detailed reports concerning some of the components of the flora have been submitted elsewhere for publication (Ash, in press; Ash and Pigg, in preparation).

## GEOLOGICAL FRAMEWORK

In Oregon, suspect terranes are exposed principally in mountain ranges and deep canyons. Elsewhere in the state, they are covered with thick layers of Cenozoic volcanic rock and alluvium. Recent work by Silberling and others (1987) shows that about 24 terranes are currently recognized in Oregon (Figure 2). The new flora occurs in the Wallowa Terrane in the northeastern part of the state and adjoining areas (Silberling and others, 1987). Until the new flora was discovered, plant fossils were known from only three of the other suspect terranes (Table 1). The oldest of the other "suspect" floras occurs in the Grindstone Terrane in central Oregon in the Spotted Ridge Formation of probable Pennsylvanian age (Mamay and Read, 1956). A small Late Jurassic suspect flora occurs in the Central Terrane along the coast in southwestern Oregon in the Otter Point Formation (Fontaine (1905b). The largest of the suspect floras occurs also in southwestern Oregon; it, however, is found in the Klamath Mountains in the Snow Camp Terrane in the Riddle Formation of Late Jurassic and Early Cretaceous age (Fontaine, 1900, 1905a).

### Wallowa Terrane

The Wallowa Terrane is exposed principally in the Wallowa Mountains in northeastern Oregon and in nearby Hells Canyon along the Oregon-Idaho border (Figure 3). As shown in Figure 2, the Wallowa Terrane is now the easternmost of the several terranes recognized in the Blue Mountains region of northeastern Oregon and western Idaho (Silberling and others, 1987). It now appears that the collage of terranes in this region originated in an intraoceanic island arc called the Blue Mountains island arc (Vallier and Brooks, 1986). According to some interpretations of available paleontological and paleomagnetic data, the Blue Mountains island arc formed in the ancestral Pacific Ocean and was displaced hundreds or even thousands of miles from where it originated. Vallier and Engebretson (1984) suggested that the source region may have

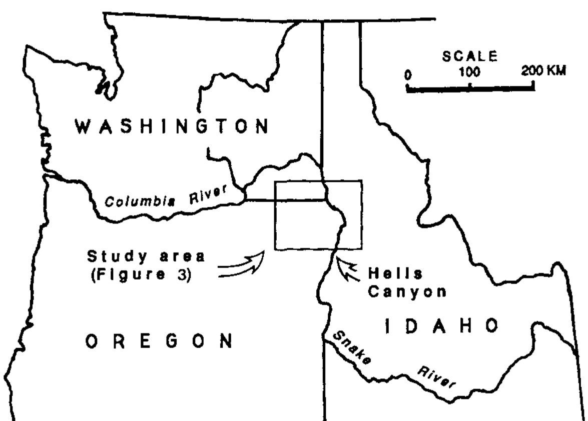


*Figure 1. Index map of the northwestern United States showing the location of the study area.*

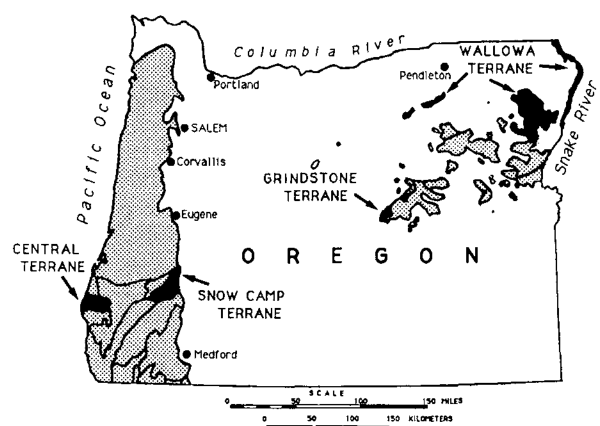


*Figure 2. Map showing where suspect terranes (shaded areas) are exposed in Oregon. The four terranes that contain plant fossils are darkly shaded and identified. Adapted from Silberling and others (1987).*

Table 1. *Suspect floras of Oregon. The locations of the several suspect terranes listed here are shown in Figure 2. The terrane nomenclature is from Silberling and others (1987)*

| Age | Area | Formation | Terrane | References |
|---|---|---|---|---|
| Late Jurassic to Early Cretaceous | Klamath Mountains, Oregon | Riddle | Snow Camp | Fontaine, 1900 |
| Late Jurassic | Southwestern Oregon | Otter Point | Central | Fontaine, 1905b |
| Middle Jurassic | Northeastern Oregon and northwestern Idaho | Coon Hollow | Wallowa | This paper; Ash, in press |
| Pennsylvanian | Central Oregon | Spotted Ridge | Grindstone | Mamay and Read, 1956 |

been in the western Pacific and that it could have been connected with Australia and New Zealand at one time. Newton (1986) and Stanley (1986) have favored a location in the eastern Pacific ocean near the equator. More recently, however, a reevaluation of paleomagnetic data by May and Butler (1986) indicates that the terranes of the Blue Mountains island arc "were at approximately their present relative latitude with respect to cratonic North America" during the early Mesozoic, although they were in a near-equatorial position. Others believe that the island arc did not shift very far from where it is now found relative to the craton (Vallier and Brooks, 1986).

Rocks in the Wallowa Terrane range from Pennsylvanian to Early Cretaceous in age and include basalt to rhyolite flow rocks, gabbro to granodiorite intrusive rocks, and abundant volcaniclastic and sedimentary rocks. In the Pittsburg Landing area of Hells Canyon, where the new flora occurs, the sequence includes the Pennsylvanian and Permian Cougar Creek Complex, the Middle Triassic Wild Sheep Creek Formation, the Upper Triassic Doyle Creek Formation, and the Jurassic Coon Hollow Formation, which contains the new flora. Here the Coon Hollow Formation is unconformably overlain by the Columbia River Basalt Group (Figures 4 and 5).

### Coon Hollow Formation

The Coon Hollow Formation is estimated to be about 500-600 m thick and is separated from the underlying Doyle Creek Formation by an angular unconformity. In the Hells Canyon area, the Coon Hollow Formation has been divided into five distinctive, but as yet unnamed, lithologic units by White and Vallier (in preparation) and White and others (in preparation). Those authors show that a unit composed of red tuff occurs at the base of the sequence (see Figure 4). The tuff unit is about 50 m thick and is unconformably overlain by a unit composed dominantly of conglomerate and sandstone. The conglomerate-sandstone unit is about 200 m thick and is thought to have been deposited in deltas and alluvial fans. It is overlain conformably by a unit composed primarily of dark sandstone and mudstone with lenses of impure limestone near the base. The sandstone-mudstone unit is about 100 m thick and apparently was deposited under marine conditions, as it contains many marine invertebrate fossils including corals, pelecypods, brachiopods, and ammonites (Stanley and Beauvais, 1990). The uppermost unit is a turbidite sequence of sandstone and mudstone that is separated by faults from the underlying parts of the Coon Hollow Formation in the Pittsburg Landing area. The fifth unit in the Coon Hollow Formation consists of andesite and diabase intrusions that occur throughout the unit.

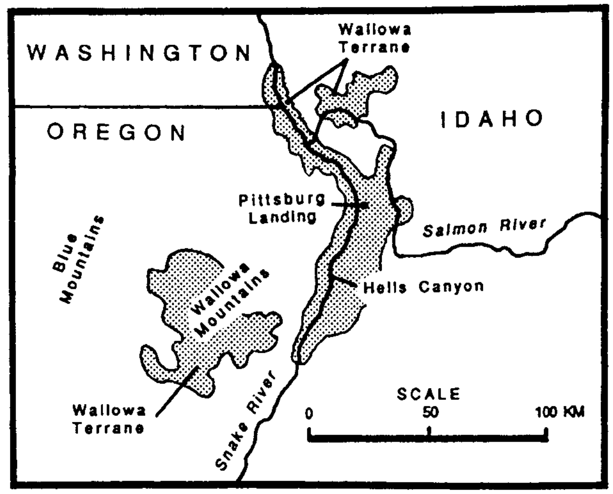


*Figure 3. Map of Hells Canyon and adjacent areas in the northwestern United States. Adapted from Silberling and others (1987).*

Plant megafossils occur mainly in the fine-grained overbank deposits in the delta to braidplain sequence in the conglomerate-sandstone unit. They also occur in the nonmarine portions of the sandstone-mudstone unit above the basal limestone lenses that contain the marine fauna described by Stanley and Beauvais (1990).

The fauna in the sandstone-mudstone unit indicates that the unit was deposited during the Bajocian Stage of the Middle Jurassic (Stanley and Beauvais, 1990). The plant fossils appear to confirm this age also.

Some of the best and most accessible exposures of the Coon Hollow Formation are present along the steep east-facing wall of Hells Canyon on the Oregon side of the Snake River at Pittsburg Landing (Figure 5). Although plant fossils occur on both sides of the Snake River in this area, many of those discussed here were collected from the exposures shown in the photograph.

## COON HOLLOW FLORA

The Coon Hollow flora consists principally of impressions of leaves, leafy shoots, and seeds plus a small amount of poorly preserved petrified wood. Generally, the fine details of the fossils are not preserved because of the coarse nature of the rocks in which they occur.

Because of its age (Middle Jurassic, about 175 million years old), the Coon Hollow flora does not contain many forms that resemble any of the living plants with which most people are acquainted. There are no broad leaves in the flora nor flowers nor grass. About the only fossils in the flora that might be familiar are some of the fern and ginkgo leaves and possibly some of the leafy coniferous shoots.

Although identification of the plant fossils to the specific level is difficult because they are so poorly preserved, it is possible to identify them to the generic level with considerable assurance. Preliminary studies indicate that the flora consists of a variety of forms representing most major plant groups except the flowering plants (Table 2). The flora is dominated by the ferns with four taxa and the conifers with four taxa. The ginkgoes are represented by several dozen specimens of one species. Seed ferns are very rare as the group is represented by only a few specimens of a single species. Oddly, the horsetails and cycadophytes also are rare, although they typically occur in abundance in many other early Mesozoic floras.

Table 2. *List of the plant fossils that have been identified in the Coon Hollow Formation of Middle Jurassic age in the Wallowa terrane in the Hells Canyon, northeastern Oregon and northwestern Idaho.*

| | |
|---|---|
| Horsetails | *Neocalamites* sp. |
| Lycopods | *Isoetites* n. sp. |
| Ferns and fernlike foliage | *Phlebopteris* n. sp.<br>*Dicksonia oregonensis*<br>*Adiantites* sp.<br>*Cladophlebis* sp. |
| Seed Ferns | *Sagenopteris* sp. |
| Ginkgoes | *Ginkgo huttonii* |
| Conifers | *Podozamites* sp.<br>*Pagiophyllum* sp.<br>*Brachyphyllum* sp.<br>*Mesembrioxylon* sp. |

### Horsetails

Living horsetails are small plants that have hollow, joined green stems. They generally live in swampy areas. In the past, they once were much more common and much larger. In the Coon Hollow flora, the horsetails are represented by a few, very poorly preserved casts of the stem called *Neocalamites.* The casts are about ½ in. in diameter and about 4 in. long and show vertical striations and the remains of one or more nodes. These fossils suggest that the Coon Hollow plants had stems that were 10 or more ft in height and were taller than most living horsetails.

### Lycopods

Lycopods are now very small, generally inconspicuous plants that have several growth habits and typically live in swampy areas. In the past, like the horsetails, the lycopods were once more common and larger. This group is represented in the Coon Hollow flora by dozens of specimens of a new species of the fossil quillwort *Isoetites.* The new *Isoetites,* like its living descendants, looks very much like a clump of grass with long narrow leaves arising from a short thick stem called a corm (Plate 1, Figure 1). Most of the specimens of this fossil that have been collected are the remains of the long narrow leaves, but a few examples of the short, thick stems and the basal fertile parts of the leaves have also been collected in addition to some of its megaspores. The leaves of this fossil are about ⅛ in. in width and probably were 1 ft or more in length. Each leaf contains a broad midrib. At one locality, the fossil occurs in great masses at several horizons. A detailed description of this new species has been submitted for publication (Ash and Pigg, in preparation).

### Ferns

Ferns typically have large, showy leaves that are divided into small segments called pinnae. The pinnae often are subdivided into still smaller segments called pinnules. In most ferns, the pinnae are arranged pinnately along the lateral margins of a stem; in a few, the pinnae radiate outward from the top of a stem in a palmate fashion. Most modern ferns live in shady areas such as forests, but a few hardy types live in the open, if adequate water is available.

The most abundant and best known fern fossils in the flora are the remains of a large palmate leaf that has been referred to a new species of *Phlebopteris* (Ash, in press). Some specimens of this leaf may have been as much as 2 ft in diameter. The pinnae, which are as much as 18 in. long and 4 in. wide arise from two short arms that occur at the tip of a stout stem (Plate 1, Figure 6). They are divided usually into many widely spaced, narrow, elongate pinnules that are up to 2 in. long and 1½ in. wide (Plate 1, Figures 7 and 8). Some specimens that have shorter and narrower pinnules are also present (Plate 1, Figure 6). The pinnules have obtusely pointed apices. Each pinnule contains a strong midrib from which lateral veins arise at a high angle and give off anastomosing branch veins. The fertile pinnae bear circular superficial sori arranged in a single row on each side of midrib, as shown in Plate 1, Figure 3. Several fiddleheads (crosiers) of this fossil also have been found (Plate 1, Figure 4) and show that the leaf "unrolled" as it matured just like its living descendants. These descendants now live in the open at various localities in the humid tropics such as Indonesia.

Other ferns in the flora include a very delicate pinnate leaf resembling *Dicksonia oregonensis* (Plate 1, Figures 2 and 5), *Adiantites* sp., and *Cladophlebis* sp. None of these is very common. They probably provided ground cover in the forests of the time.

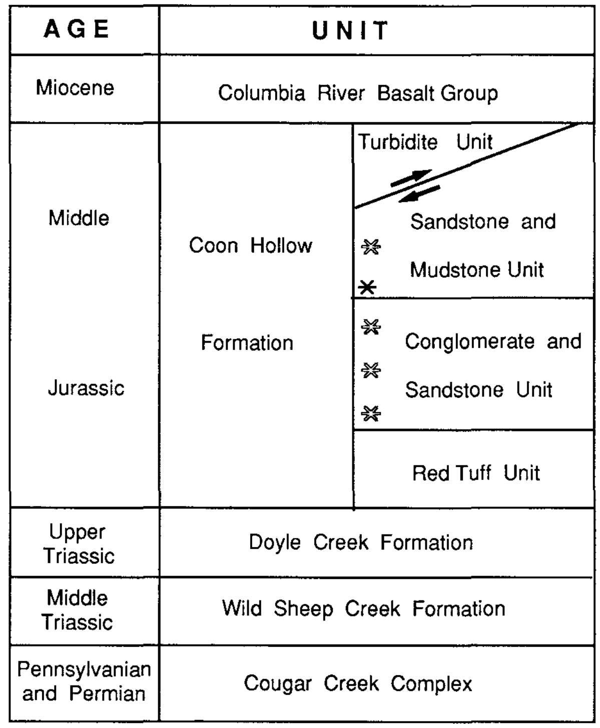


*Figure 4. Stratigraphic section of the pre-Quaternary strata exposed in the Pittsburgh Landing area of the Hells Canyon, Idaho and Oregon. The open asterisks indicate the approximate stratigraphic position of plant localities in the Coon Hollow Formation. The solid asterisk indicates the approximate position of the Middle Jurassic invertebrate fauna described (Stanley and Beauvais, 1990) from the formation.*

### Seed ferns

The now-extinct seed ferns were plants that reproduced by means of seeds and often had fernlike leaves. They were very common in the Paleozoic but began to decline in the early Mesozoic and eventually became extinct in the Cretaceous. These plants were somewhat uncommon in the Jurassic, so it is not surprising that the rarest plant fossils in the Coon Hollow flora are the remains of a seed fern. This seed fern is called *Sagenopteris* and is represented in the flora by three ovate leaves which are a little over 1 in. long and about 1 in. wide (Plate 2, Figure 3). The leaves contain a strong midrib from which abundant narrow anastomosing veins arise at frequent intervals and pass obliquely to the margins.

*Plate 1. 1. Leaves and upper part of the corm (stem) of* Isoetites *n. sp., x1. 2 and 5. A portion of the highly dissected leaves of the fern* Dicksonia oregonensis, *x1. 3. Fragments of the fertile pinnules of the fern* Phlebopteris *n. sp. bearing a row of round sori on either side of the pinnule midrib, x1. 4. Fiddlehead of* Phlebopteris *n. sp., x1. 6. The lower part of several pinnae of* Phlebopteris *n. s. where they join the basal arms of the leaf, x1. 7. Portion of a sterile pinna of* Phlebopteris *n. sp. in which the pinnule midribs are clearly visible, USNM 448764B, x1. 8. Large fragment of a typical sterile pinnae of* Phlebopteris *n. sp. Note that some of the pinnules are curved, suggesting that they were rather flexible when living, USNM 448766A, x1.*


*Figure 5. East-facing cliff of Hells Canyon at Pittsburg Landing. The Snake River is visible in places at the base of the cliff. The buildings near the river in the lower center are part of a USDA Forest Service facility. The buildings to the left on a terrace about 300 ft above the river are the remains of the Circle C Ranch. The more or less horizontal beds of the Columbia River Basalt Group (Tc) are visible in the upper right of the photograph. The Coon Hollow Formation (Jc) dips to the south in this area and unconformably underlies the Columbia River basalt.*

### Ginkgoes

This family was widely distributed during the Mesozoic, but for some unknown reason it declined abruptly during the Cenozoic and is now represented by the single species *Ginkgo biloba*. It is a hardy shade tree that has a distinctive fan-shaped leaf that often has a shallow notch on the outer margin. Somewhat similar fan-shaped leaves occur in the Coon Hollow Formation, but they are divided into several segments. Therefore, they are placed tentatively in the fossil species *Ginkgo huttonii*. This species is represented in the flora by a moderate number of leaves that range from 2 to 3 in. in diameter. They are divided into as many as a dozen segments that are up to ⅓ in. in width and 1½ in. long (Plate 2, Figures 10-12).

### Cycadophytes

A few fragmentary imprints of cycadophyte leaves are present in the flora (Plate 2, Figures 1 and 2). Enough is present, however, to show that the leaves are pinnate and have rectangular leaflets about ¼ in. wide and a little over 1 in. long. The pinnae show parallel venation, but details of the attachment area are unclear. It is difficult to identify the fossils with much assurance, but they do seem to resemble *Pterophyllum* and *Zamites*.

### Conifers

The flora contains several types of coniferous foliage that resemble that of certain living conifers, such as junipers. The leaves in these fossils are usually less than ⅛ in. in length, have sharp points, and closely clasp the stems. They are best assigned to the fossil genera *Pagiophyllum* (Plate 2, Figure 4) and *Brachyphyllum* (Plate 2, Figure 5).

The flora also contains a conifer that has large linear leaves that are about ½ in. wide and up to 5 in. long (Plate 2, Figure 8). The leaves have sharply pointed apices and contain prominent parallel veins. These leaves arise in a helical pattern from a stout stem. They are referred to the fossil genus *Podozamites*.

All of the petrified wood in the flora that has been examined thus far is coniferous and is assigned to the fossil genus *Mesembrioxylon*. Fragments of wood up to about 1 ft in diameter and 6 ft long have been observed in the formation. The wood is composed entirely of tracheids and does not contain resin ducts. The rays are narrow and high. In cross section, the wood shows narrow (as much as 1⁄16-in.-wide), well-defined growth rings with many layers of early wood and only a very few layers of late wood cells.

### Other plant fossils

Several different types of seeds also occur in the formation (Plate 2, Figures 6, 7, and 9), but it is not possible to relate them to any fossil plant as yet. Typically they are oval in outline and range from ⅓ to ¾ in. in length. The surfaces generally are smooth and featureless.

## CORRELATION

In general aspect, the Coon Hollow flora does seem to correlate more closely with the several Jurassic floras that were described many years ago from other suspect terranes in western North America than with the early Mesozoic cratonic floras that are known from the same region. The Coon Hollow flora seems to be closest to the Upper Jurassic-Lower Cretaceous Riddle flora of southwestern Oregon (Fontaine, 1905a) and the Upper Jurassic Monte de Oro and Oroville floras of northern California (Fontaine, 1900; Fry, 1964). It also has a few forms in common with Lower Jurassic flora found in the Matanuska Valley of Alaska (Knowlton, 1916). However, the Coon Hollow flora also contains several forms that are not known in any of these floras. Such forms include *Phlebopteris* and *Isoetites*, both of which are very common in the Coon Hollow flora.

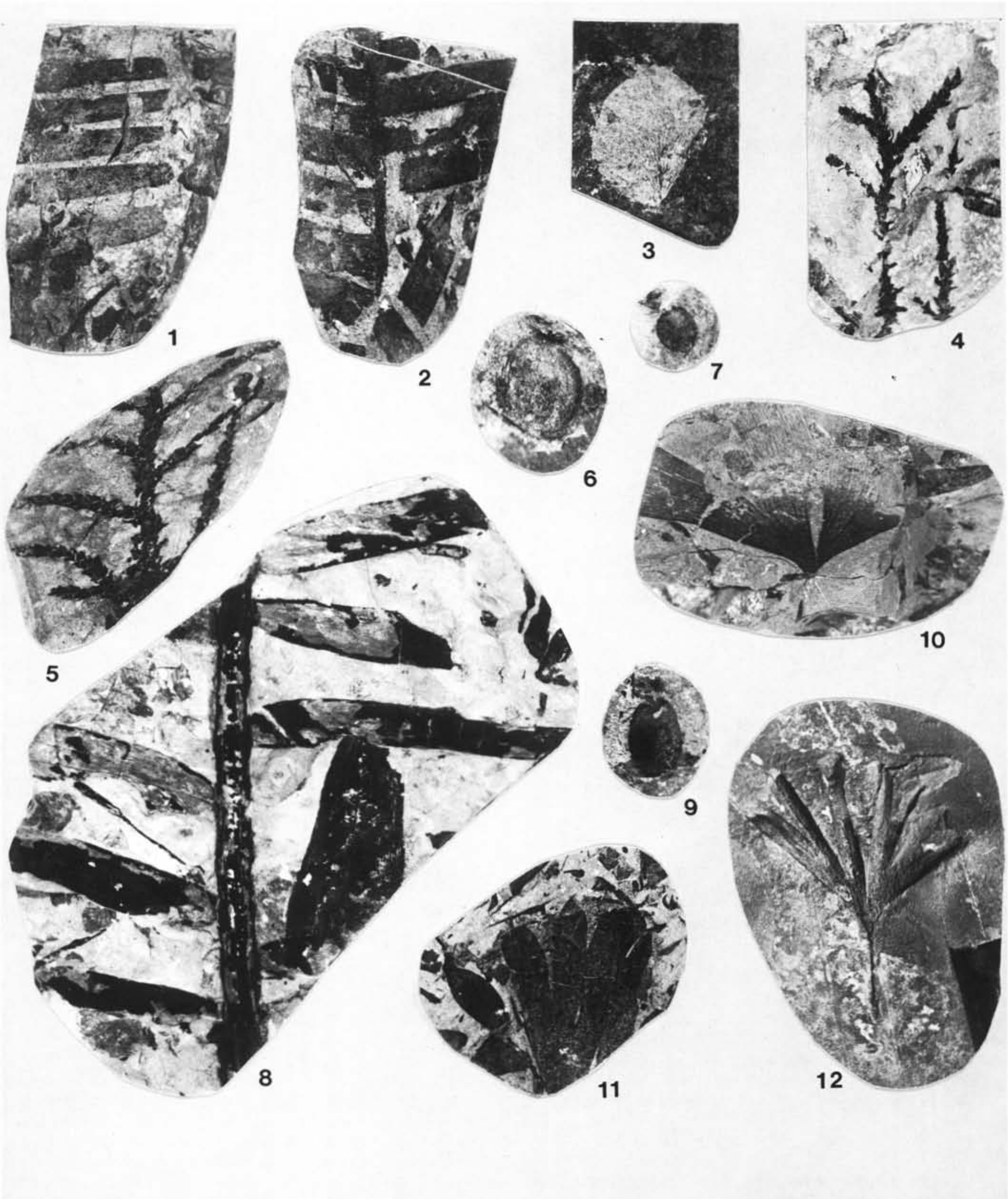


*Plate 2. 1 and 2. Fragments of two unidentified cycadophyte leaves, x1. 3. A leaflet of the seed fern* Sagenopteris. *The net venation which is typical of this species is visible along the midrib of the fossil, x1. 4. Portion of a leafy shoot of the conifer* Pagiophyllum. *Note the resemblance of the small leaves to the leaves of the living juniper, x1. 5. Fragment of a leafy shoot of the conifer* Brachyphyllum, *x1. 6, 7, and 9. Selection of the unidentified seeds that occur in the Coon Hollow flora, x1. 8. Fragment of the leafy shoot of the conifer* Podozamites. *The parallel venation is visible in the large leaves, x1. 10-12. Fragments of three fan shaped leaves of* Ginkgo huttonii. *Note the narrow segments in the leaf in Figure 12, x1.*

The Coon Hollow flora does not compare at all closely to the few early Mesozoic floras known from the cratonic portion of western North America. For example, the very well-known Upper Triassic floras that have been described from many localities in the southwestern United States by Ash (1980) are not at all similar to the Coon Hollow flora. This is also true of the several Upper Jurassic floras described from the craton in the western United States by Brown (1972) and Lapasha and Miller (1985) and western Canada (Bell, 1956).

## PALEOCLIMATIC IMPLICATIONS

The fossil plants in the Coon Hollow Formation indicate that there were several distinct nonmarine environments present on the islands in the Blue Mountains island arc. The abundance of ferns like *Dicksonia oregonensis* and the large size of some of them (e.g., *Phlebopteris* sp.) indicate a moist habitat such as along streams and lakes. This is also suggested by the horsetails and quillworts. In fact, the quillworts probably lived in shallow lakes and marshes. In contrast, the conifers such as *Podozamites* sp., *Pagiophyllum* sp., and *Brachyphyllum* sp. probably inhabited somewhat higher areas, as they required a somewhat drier environment than the ferns. *Ginkgo* generally is considered to be an indicator of dry climates also (Barnard, 1973), and the fossil probably lived in an environment similar to the environment in which the conifers lived.

The petrified wood in the Coon Hollow flora is of particular interest because considerable paleoclimatic information can be deducted from its anatomy. For example, the growth rings it shows indicate that the trees grew in an area that had strongly developed seasons such as those that typically occur in temperate regions of the world (Creber and Chaloner, 1984). Broad early wood suggests that there was abundant rainfall during most of the growing season, and narrow late wood indicates that there was only a relatively short dry season before growth ceased for the year. This interpretation is supported by the invertebrate fossils found in the unit (Stanley and Beauvais, 1990).

The plant fossils probably represent several environments and were washed into the area where they were preserved, thus constituting what is often called a "death assemblage". Many of the fern leaves (e.g., *Phlebopteris* sp.) in the flora are large, and because of their rather delicate nature it is difficult to believe that they could have been transported a very great distance before burial. Presumably, the ferns grew in a wet environment along the banks of the streams that deposited the formation, and the quillworts grew in shallow lakes and in marshes close to where they are now found. The condition of the coniferous foliage and its abundance in the flora imply that the parent plants probably grew close to where they have been found, but since conifers typically grow in somewhat dry areas they probably inhabited the hills in the area. The fragmentary condition of the petrified wood in the flora indicates that it was washed into the area from a more distant source.

## CONCLUSIONS

The newly discovered flora in the Coon Hollow Formation confirms that a portion of the Blue Mountains island arc was exposed above sea level and was occupied by a small but varied land flora. The land mass was large enough to contain a variety of nonmarine environments that included lakes, marshes, and rivers. There were also drier environments on higher ground a short distance from the streams. The plant fossils indicate that, during the Middle Jurassic, the Blue Mountains island arc was at a position in the ancestral Pacific Ocean within the temperate zone where there were well-developed but frost-free seasons and considerable rainfall.

## ACKNOWLEDGMENTS

I am grateful to Tracy L. Vallier of the U.S. Geological Survey (Menlo Park) for bringing the Coon Hollow flora to my attention and encouraging me to study it. I also thank Tracy, Charles N. Miller, Jr., and George D. Stanley, Jr. (Missoula) for their constructive criticisms of this paper and River Ranger Roy Lombardo of the USDA Forest Service for his assistance and hospitality while I was collecting in Hells Canyon. This research was supported by a grant from the Earth Science Section, U.S. National Science Foundation (NSF Grant EAR-88-04130).

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*(Continued on page 45, **Flora**)*

# Prehistoric buried forests of Mount Hood

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**ABSTRACT**

Mount Hood has experienced three major eruptive periods over the last 2,000 years. Lahars, pyroclastic flows, and fluvial reworking produced enough clastic debris during each period to overwhelm and bury the coniferous forests covering valley floors and the lower slopes of the mountain. Erosion has exposed these buried forests, most of which are in a good state of preservation, in at least six locations: (1) on the south side of Illumination Ridge north of Paradise Park (the Stadter buried forest), (2) near Twin Bridges campground on the Zigzag River (two separate forests are found here), (3) in the upper White River canyon near Timberline Lodge, (4) all along the Sandy River from Old Maid Flat to the community of Brightwood, (5) in the bed of the Zigzag River near Tollgate Wayside, and (6) along the lower Sandy River downstream from Marmot Dam.

**INTRODUCTION**

During the last 2,000 years, there have been three major eruptive periods at Mount Hood (Crandell, 1980; Cameron and Pringle, 1986, 1987). In order of decreasing age, they are the Timberline eruptive period, which lasted from about 1,800 to 1,400 years before the present (ybp); the Zigzag eruptive period, from 600 to 400 ybp; and the Old Maid eruptive period, which lasted from about 1760 A.D. to 1810 A.D. (Cameron and Pringle, 1987). During all three periods, the eruptive center was located high on the south-west flank of the mountain near the composite dacite dome known as Crater Rock. This location, bounded as it is by Steele Cliff on the east, the summit ridge to the north, and the upper portions of Illumination Ridge on the northwest, limited distribution of the eruptive products (excluding tephra) to the drainages of the Sandy, Zigzag, and White Rivers.

The eruptive style during all of the eruptive periods was virtually identical. Viscous dacitic lava reached the surface through the post-glacial vent and piled up to form a composite dome. The steep slopes in the vicinity of the vent helped initiate repeated collapse of the still-hot dome rock onto the lower slopes of the mountain, burying the existing topography and forming the smooth debris fan that gives the southwest side of the mountain its distinctive shape. When these slopes were covered with snow, the avalanches of hot rock created snow-melt water that mixed with loose debris to form lahars capable of traveling many miles along rivers leading from the mountain. Deposits from these lahars can be found at the confluence of the Sandy and Columbia Rivers near Troutdale, over 56 mi from the mountain, and in Tygh Valley along the White River, a flow path of over 47 mi (Cameron and Pringle, 1987). When the rock was hot and gas-rich enough, pyroclastic flows that traveled at least 5.6 mi down the White River and 8 mi along the Zigzag River were produced (Cameron and Pringle, 1987).

On the steep upper slopes of the mountain, clastic flows can attain impressive velocities (a pyroclastic flow erupted about 1800 A.D. into the White River canyon had a calculated velocity of 85 mi/hr [Cameron and Pringle, 1987]). In these locations, any tree encountered by a flow would be pushed over in a downstream

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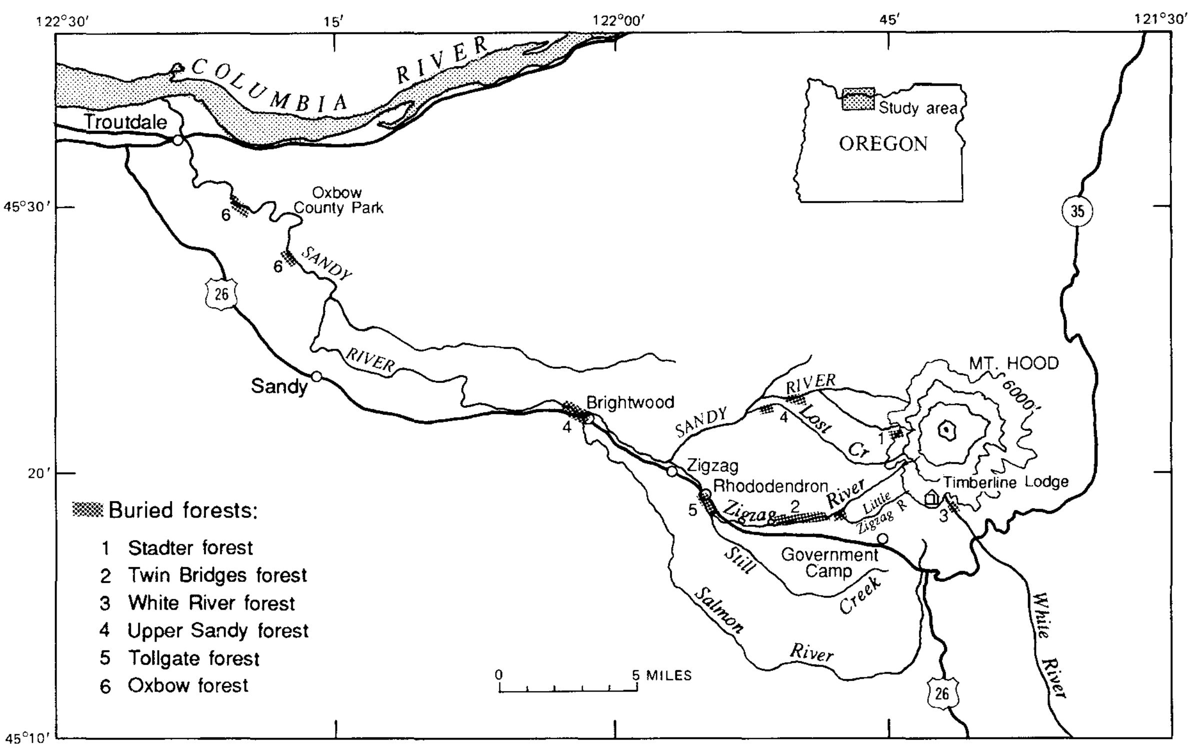



*Figure 1. General location map to the known buried forests of Mount Hood.*

direction or snapped off and carried away by the flow. Farther from the vent where slopes are more gentle and velocities are lower or in the mouths of tributary valleys where backwater flooding occurred, the flows would move passively among tree trunks, bury their roots and lower trunks, and eventually kill the trees.

Deposits left behind by these flows are generally coarse grained and massive. Near the mountain, boulders up to 6 ft across can be found suspended in a matrix of sand and gravel. With increasing distance from the source, the size of the largest clast drops steadily. At Brightwood, roughly 18 mi from the vent area, Old Maid-age deposits are composed of coarse sand and gravel with an occasional cobble up to 10 in. in diameter. Near Oxbow County Park, approximately 44 mi from the source, deposits from the same flow are composed of sand to coarse sand with some gravel lenses. At the town of Troutdale, at least 50 mi from the mountain, only thick, cross-bedded deposits of medium sand are found.

Preservation of the buried trees is, for the most part, a function of water. If there is sufficient water to keep the buried wood moist but not saturated, the wood will decay rapidly, and the tree may cease to be recognizable after only a few decades (for Douglas fir, 50 to 75 years; for western red cedar, 75 to 125 years [Franklin and others, 1981]). In drier environments or where the wood is constantly water-saturated, decay is greatly slowed, and trees may last for hundreds of years. Therefore, most of the buried forests are found high on the mountain in relatively dry environmental zones or directly adjacent to rivers where the trees were constantly below the local water table.

## THE BURIED FORESTS

Six prehistoric buried forests have been discovered at Mount Hood to date (Figure 1). (Any reader who knows of others not mentioned in this article is asked to contact the authors.) The forests range in location from less than 2½ mi from the vent area at an elevation of 5,850 ft to over 44 mi away at an elevation of less than 50 ft. In time they range from over 1,700 ybp to less than 200 ybp. Only one forest has been named, and that one only unofficially (the Stadter buried forest [Hodge, 1931]). For convenience, the forests will be referred to here as (1) the Stadter buried forest, located at the 5,850-ft level below the terminus of Zigzag Glacier; (2) the Twin Bridges buried forest, upstream from the site of the old Twin Bridges Campground on the Zigzag River; (3) the White River buried forest, easily seen from the "Buried Forest Overlook" just east of Timberline Lodge along the Timberline Trail; (4) the Upper Sandy buried forest, found along the upper Sandy River from the Ramona Falls trail to the town of Brightwood below the confluence with the Zigzag River; (5) the Tollgate buried forest, along the Zigzag River just upstream from Tollgate Wayside; and (6) the Oxbow buried forest, along the lower Sandy River from just downstream of Oxbow County Park to near Indian John Island. Of the six, only the Stadter and Oxbow forests require more than a short walk to be seen.

### Stadter buried forest

The Stadter buried forest is the only one with a previously published detailed history (Hodge, 1931). First seen in 1926 by Fred W. Stadter, a Portland judge, and investigated a few years later by members of the Mazamas climbing club, the Stadter buried forest is located on the south side of Illumination Ridge at the 5,850-ft level. Hodge originally reported the elevation as 6,200 ft, which almost made the authors miss the forest during a search for it in the summer of 1988. The 5,850-ft figure was checked by altimeter, and the altimeter was checked against the benchmark on the steps of Timberline Lodge, both at the start and end of the hike. It is perhaps the original mistake in elevation that led to the original interpretation by Hodge that this forest existed higher on the mountain than trees now live (modern timberline is around 6,000 ft). He deduced that warm fogs and rains produced by volcanic activity near Crater Rock created a micro-environment capable of supporting a forest and also kept the glaciers at bay. When volcanic activity ceased, the glaciers advanced and overran the forest.

This forest is reached only after a hike of at least 7 mi (Figure 2). To get there, follow the Timberline Trail (also marked as the Pacific Crest Trail or Trail No. 2000) west from Timberline Lodge to Paradise Park. From the north end of the Park, take off cross-country, angling uphill and northward to the edge of the deep canyon that drains Zigzag Glacier. The forest is exposed across the canyon above the local tree line as a line of logs sticking out of the canyon wall about 5 ft below the top of the wall on the upstream end and about 40 ft below the top at the downstream end (the horizon containing the logs dips at a steeper angle than does the top of the ridge). To actually reach the logs of the forest takes considerably more effort. At least 500 ft of elevation must be gained before the canyon is shallow enough to be crossed safely, allowing access to the top of the ridge on the other side. Most of the trees protrude from the nearly vertical face of the canyon wall, but near the upstream end of the exposure where the log horizon comes close to intersecting the ridge top, they can be seen close up.

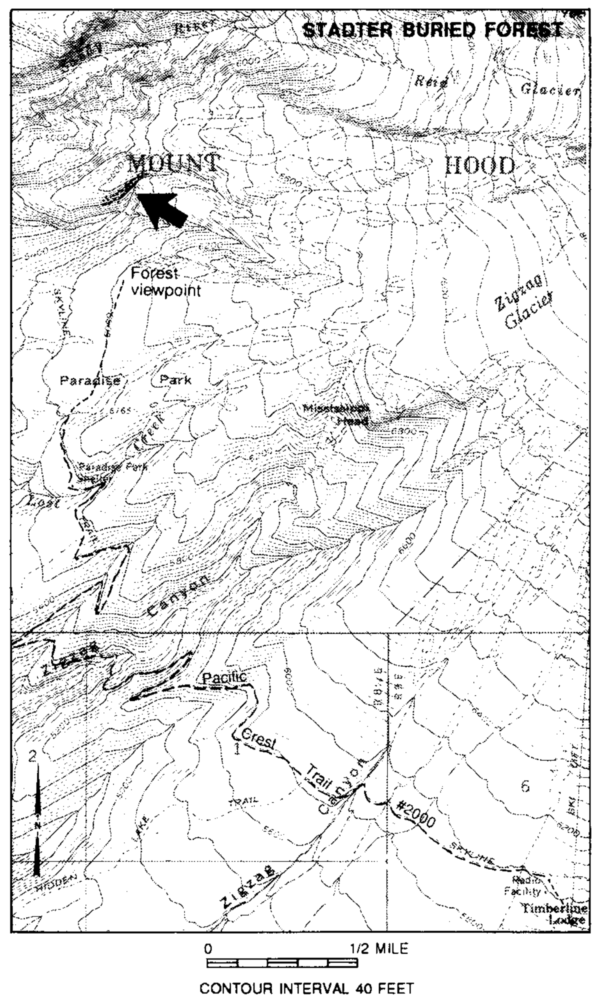



*Figure 2. Location (stippled area in northwest quadrant of map) and access map for the Stadter buried forest. Base is from Mount Hood South 7½-minute quadrangle.*

*Figure 3. View across the canyon to the Stadter buried forest. The trees grew in soil developed on the light-colored rocks of a lava flow.*

Between twenty and thirty logs averaging 1 to 2 ft in diameter are exposed along approximately 100 ft of the canyon wall (Figure 3). All are prone, are aligned more or less due west, and show considerable abrasion on their surfaces. All are in an extremely good state of preservation, due probably to the elevation, which keeps them frozen for much of the year, and their southerly aspect, which keeps them relatively dry the remainder of the year. The logs are lying on or within a foot or so of the top of a buried brown soil/colluvium layer that represents the ground surface of the time when the trees were alive. This soil developed on the surface of a thin lava flow that caps a thick sequence of steeply dipping clastic debris. The soil is easily traced for several hundred feet downstream and shows that the surface on which the trees grew was uneven and rolling. Overlying the soil are the layers of clastic volcanic debris that buried the forest, mostly laharic deposits but also a few pyroclastic flow deposits. These latter deposits are identified by the abundance of iron oxide staining, increased induration, and the presence of radially fractured clasts. Both the lahars and the pyroclastic flow deposits parallel the average gradient of the modern ground surface and commonly truncate against the undulating top of the buried soil layer. Wood samples from these logs have been dated at 1,700±70 radiocarbon years (Donald B. Lawrence, written communication, 1989), placing their burial near the middle of the time range for the Timberline eruptive period. Contrary to the original interpretation by Hodge (1931), these trees were buried by eruptive processes, not by glacial action.

**Twin Bridges buried forest**

There are actually two forests located here, one above the other, eroding out of a 25-ft-high terrace along the Zigzag River at the 2,820-ft elevation. Although the trees are exposed along the original route of Highway 26 and must have been seen by thousands of people, they have been described in only a limited way: the older (lower) forest was first described by Donald and Elizabeth Lawrence (1959), and the younger (upper) was mentioned briefly by the authors (Cameron and Pringle, 1986).

The older forest consists of half a dozen or more vertical snags sticking out of the talus along the right bank (right and left banks of a river are determined by assuming that the observer is always

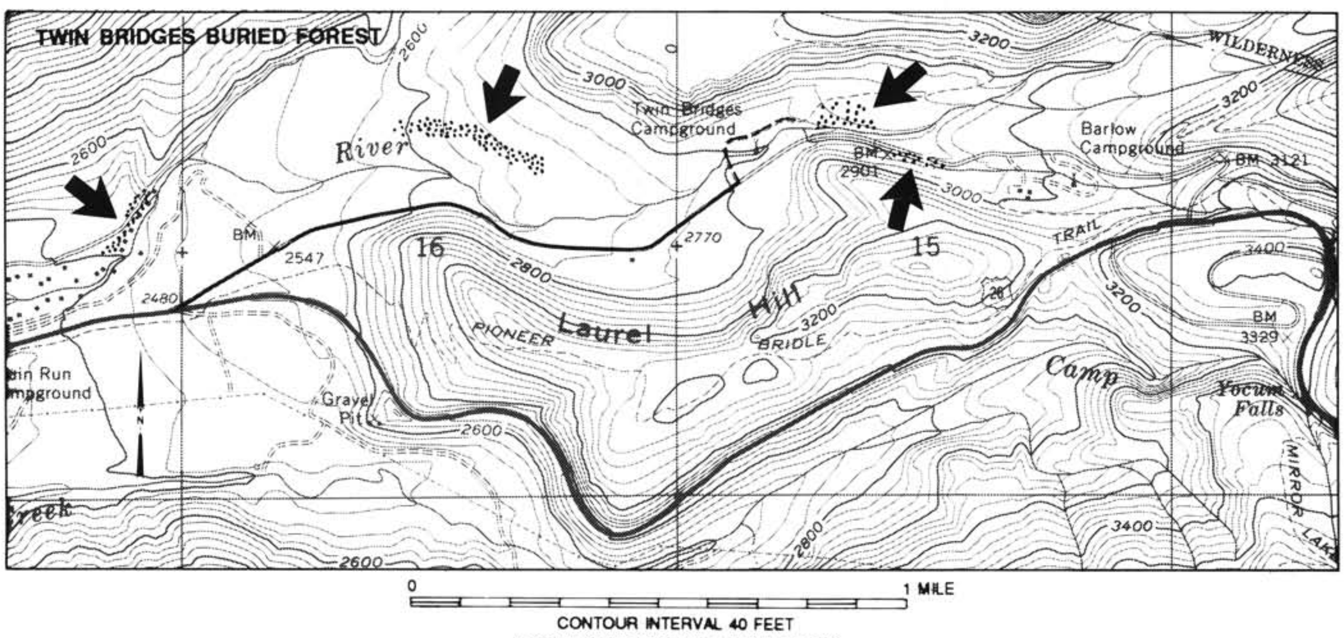



*Figure 4. Location (stippled areas) and access map for the Twin Bridges buried forest. Base is from Government Camp 7½-minute quadrangle.*

facing downstream) of the Zigzag River less than a quarter mile upstream from the site of the old Twin Bridges campground (Figure 4), now the trailhead for the Paradise Park trail. To get there, follow the trail upstream for about 100 yd and then head cross-country back to the river. The trees are exposed in a 25-ft-high cut bank that drops right into the Zigzag River. The old highway can be seen across the river on the left bank 10 ft above river level. There is a thick growth of young alder trees growing along the edge of the river that may hide the snags somewhat. The snags can also be seen from the old highway, especially during winter when the leaves are gone from the alders. Drive past the turnoff to the trailhead about a quarter mile until you can see the river to the left through the fringe of alders. You should be able to glimpse the snags through the trees despite their progressive burial by talus.

The older trees have been dated twice by the radiocarbon method with a considerable discrepancy in the results: the first date of 920±150 ybp by the Lawrences (1959), and the second of 550±130 ybp by the authors (Cameron and Pringle, 1986). Some of the discrepancy can be resolved by looking at the techniques used in obtaining the two dates. In obtaining the older date, the Lawrences were concerned about contamination from modern fungi and mold in the rotting outer layers of the trees, so an axe was used to chop into the interior of the tree to find unaltered, but older, wood. Sampling the older wood may have caused some of the discrepancy in dates, how much depending on the depth into the tree from which the sample came. Modern analytic laboratories now claim to be able to eliminate, or at least reduce, modern contamination through various cleaning processes. Our samples were taken from the first two or three rings below the bark in order to date, as closely as possible, when the tree died. If some modern carbon escaped the cleaning process, the second date could be too young. However, the second date correlates well with other radiocarbon dates from the Zigzag eruptive period. A lahar near the Upper Sandy Guard Station was dated at 455±135 ybp and tephra on the Muddy Fork at 560±150 ybp (both dates from Cameron and Pringle, 1986). Therefore we believe that this forest was buried by debris from the Zigzag eruptive episode.

The exposed trees in the lower portion of the Twin Bridges buried forest are Douglas firs, some of which are in an advanced state of decay (Figure 5). All still have their bark, even on the upstream sides, attesting to a generally passive burial. They are buried in a sequence of bouldery, fines-depleted flood deposits and volcanic debris flows. The top of the sequence is marked by sand and silt layers probably formed from reworking of debris upstream by post-eruption stream flow. This sequence of sediments resulted from volcanic activity during the Zigzag eruptive period, when the next-youngest dome growth episode after the Timberline eruptive period occurred. The Zigzag period was much smaller volumetrically than the Timberline, and the deposits here are the thickest yet found of this age on the mountain. The deposits are found here in a river basin with a very small catchment area near the vent, which may indicate that the eruptive activity was centered in an area "facing" the catchment, such as the downslope side of Crater Rock.

The passive nature of the initial burial of the exposed trees, as indicated by their intact bark, may be a function of distance from the original river channel. At least two snags are actually in the Zigzag River, indicating that the river was in another location at the start of the eruptive period. The height of the terrace that contains the Zigzag-age outcrop and its proximity to the right valley wall suggest that the channel was south of its present location, closer to the center of the valley, and that the snags were part of a forest growing on a low terrace or flood plain. As debris filled the main channel and the flows spilled out of the channel and through the trees, they lost much of their velocity and left the trees relatively unscarred.

This site has the distinction of possessing buried forests of two separate ages. Above the layered sands and silts at the top of the Zigzag-age section is a soil zone about a foot thick, topped by a lahar deposit and finally the modern soil layer. The buried soil layer supported a mixed forest of firs and cedars that was buried and killed by the single debris flow. Exposed in the outcrop along the Zigzag River are a few Douglas fir stumps and roots of various unidentified plants. Standing snags of cedar can be found back from the top of the bank and along the highest terrace in the campground and downstream to the confluence with Lady Creek. These snags are in a fairly advanced state of decay; all have lost their bark and an unknown thickness of outer wood. Nevertheless, the outermost layers available have been dated by radiocarbon methods at 270±150 ybp (Cameron and Pringle, 1986), indicating they were killed by debris flows produced by the most recent major eruptive episode, the Old Maid eruptive period.

After cessation of the Zigzag eruptions, the floor of the Zigzag valley was probably fairly flat and filled to a depth even with the top of the Zigzag-age deposits. Trees immediately began to take root across this surface, expanding outward from the seed sources along the untouched valley walls. Within a hundred years or so, a mixed conifer forest once again covered the streambanks. The Old Maid eruptive period began around 1760 A.D. (based on preliminary dendrochronologic work done around the mountain by the authors), but due to the location of the vent (apparently on the upslope side of Crater Rock), the vast majority of eruptive debris was directed into the White River and Sandy River drainages. Only a single lahar of this age is known to have entered the Zigzag River drainage. The lahar covered the valley floor to an average depth of 3 ft in the vicinity of the Twin Bridges buried forest and killed the trees growing on the old Zigzag-age surface. The firs rotted away rapidly in the moist environment of the deep, shaded valley and are found only as root mats and stumps buried

*Figure 5. Two trees in the Zigzag-age portion of the Twin Bridges buried forest.*

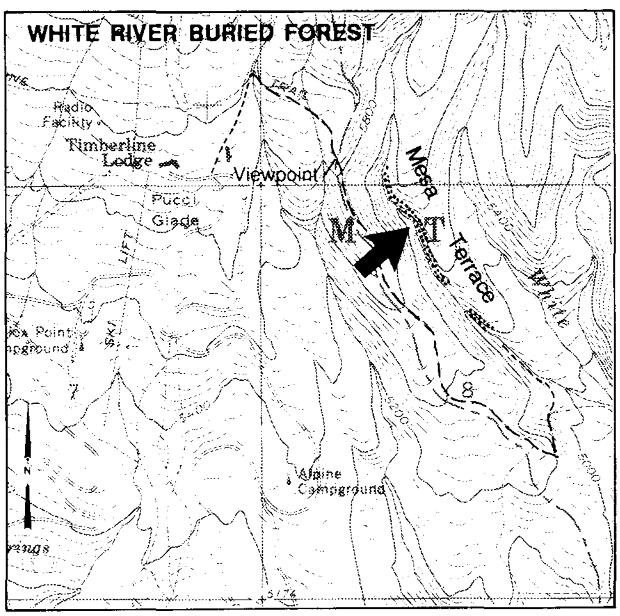
in the debris flow deposits. The cedars rotted much more slowly and can still be found as isolated snags 6 to 10 ft tall.

### White River buried forest

This forest has been mentioned in passing at least three times in scientific literature (Lawrence and Lawrence, 1959; Crandell, 1980; Cameron and Pringle, 1987) but has never been given the attention that it deserves. Locally, it is sometimes known as the "Buried Forest" or "Ghost Forest," though the latter name has also been applied to the stand of dead trees flanking either side of the White River canyon near timberline that were killed but not buried by a hot tephra fall during an Old Maid-age eruption (Lawrence, 1948; Cameron and Pringle, 1987).

An easy hike gives an overview of this forest, located near the bottom of White River canyon east of Timberline Lodge at an elevation of between 5,000 and 5,500 ft. To get there, head east from the lodge along the Timberline Trail for about a quarter mile to the Buried Forest Overlook (Figure 6). Here the trail skirts along the top of the canyon wall and provides an unobstructed view of the buried trees, seen as individual snags sticking out of the steep exposure of the valley fill material 500 ft below your feet. Between 10 and 15 snags scattered along 400 or 500 yd of the exposure can be seen from the overlook. A closer examination of these trees can be made by following the trail for about a mile and a half to the bottom of the White River canyon and then walking upstream to the beginning of the exposure. Beware of rockfall from the steep valley walls if you decide to do this.

The trees of the White River buried forest, identified by Lawrence and Lawrence (1959) as mountain hemlock, were buried by volcanic deposits during the Old Maid eruptive period. These trees have yielded radiocarbon dates ranging from 185±120 ybp (Cameron and Pringle, 1986) to 260±150 ybp (Crandell, 1980) and were probably killed during some of the first eruptive pulses of the Old Maid period. The trees are rooted in a much older soil layer that appears to be formed on glacial material rather than volcanic deposits from the older Holocene eruptive periods. In fact, no post-glacial volcanic material other than Old Maid-age has yet been found in the upper White River drainage.




0 1/2 MILE

CONTOUR INTERVAL 40 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

*Figure 6. Location (stippled area) and access map for the White River buried forest. Base is from Mount Hood South 7½-minute quadrangle.*

Most of the obvious topography in the upper White River canyon is the product of glacial action. The Buried Forest Overlook is situated on a right lateral moraine from a major glacial advance, and at least three left lateral moraines are visible across the canyon as knife-edged ridges. Before the start of the Old Maid eruptions, the valley between the innermost moraines was probably broadly U-shaped and covered by a forest of hemlock. Debris from the first Old Maid-age eruptions began filling the valley with bouldery deposits. Many of the trees in this buried forest still have their bark intact, indicating that the material was deposited in a low-energy situation; however, they are no longer in their normal vertical orientation. They are, instead, inclined in a downstream direction by up to 30°, indicating that deposition, though passive, was forceful enough to push the trees over slightly. The snags are also of a uniform height, between 3 and 5 ft, which may represent a hiatus in deposition after the trees were buried to this depth. A pause of a few years would have allowed the portion of the trees above ground to start to decay or at least desiccate and become brittle. When eruptions started again, new deposits would have broken the trees off near ground level, forming snags of a uniform height.

The Old Maid-age eruptions filled the White River valley to a depth of around a hundred feet. Subsequent erosion by two streams draining White River Glacier cut through the deposit on either side of the valley, exposing the buried trees and leaving a flat-topped remnant in the valley center known as Mesa Terrace. The trees of this forest are in such a fine state of preservation that they are prime candidates for dating using dendrochronologic techniques (a study that is just beginning) and should provide a definite date for the start of the Old Maid eruptive period.

### Upper Sandy buried forest

The Upper Sandy buried forest is the most extensive on Mount Hood. Trees can be found eroding out of streamside terraces in an almost continuous strip along the Sandy River from near Ramona Falls in the Mount Hood Wilderness Area downstream to the community of Brightwood. It should be noted that, except for the area actually on Old Maid Flat (within the boundaries of Mount Hood National Forest), much of this forest is on private land, and care should be exercised to respect the rights of the landowners. The cedar snags of the Old Maid Flat area have been mentioned previously in the scientific literature (Crandell, 1980; Cameron and Pringle, 1986, 1987). They have even been mentioned in a river-running guide (Willamette Kayak and Canoe Club, 1986, p. 143), though they were mistaken for pilings driven into the river bottom.

The most easily reached areas in which to see remnants of this forest are on Old Maid Flat, specifically in the Lost Creek picnic area, and along the Ramona Falls trail between the falls and the junction with Portage Trail, and in the lower valley of the Clear Fork (Figure 7). The Lost Creek picnic area is a little less than 3 mi up Old Maid Flat from the turnoff from the Lolo Pass road. The route is well marked, and the road is paved all the way, but the last half is a one-lane road with turnouts, so watch for oncoming traffic. The picnic area is designed for use by the handicapped and has paved, level trails suitable for use by wheelchairs. (As of this writing [1990], the area is being expanded to include wheelchair-access campsites.) The trees in this part of the buried forest are exposed, for the most part, in the bed of or directly adjacent to Lost Creek. Follow the trail upstream from the parking area for the best views.

At least 20 snags have been located along this reach of Lost Creek. All are conifers, ranging in diameter from 1 to 4 ft and in height from 2 to 10 ft. Most show little sign of abrasion during burial, and many still possess their bark. Constant saturation by the waters of Lost Creek has kept the portions of the trunks near

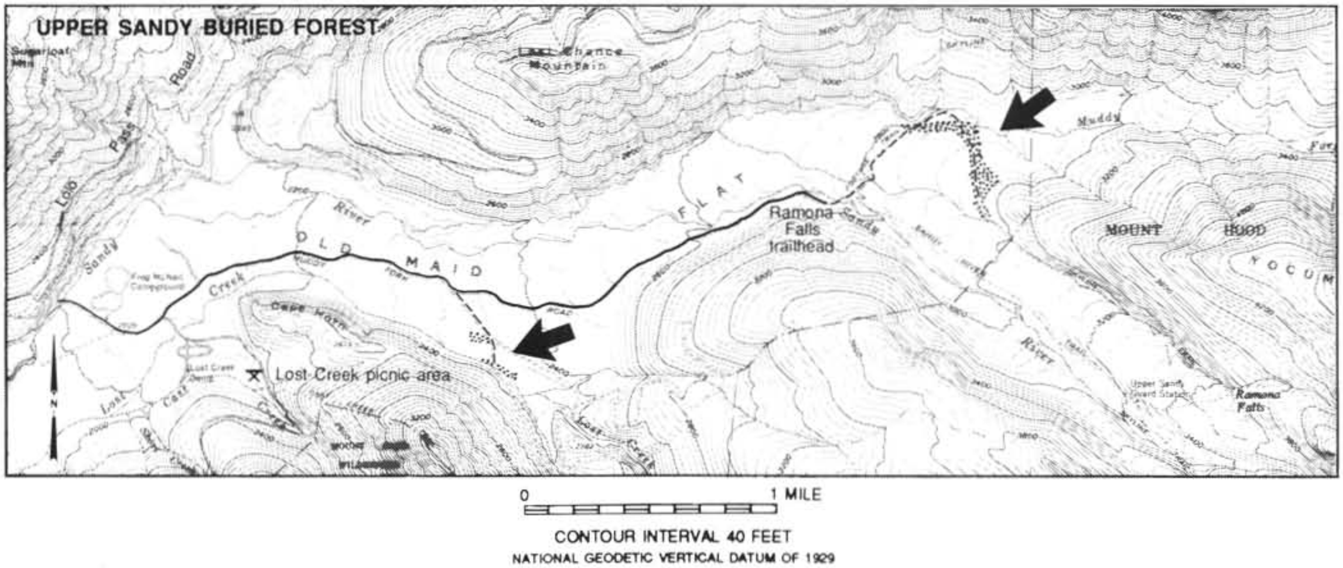



*Figure 7. Location (stippled areas) and access map for the Upper Sandy buried forest. Base is from Bull Run Lake 7½-minute quadrangle.*

water level in a good state of preservation, but their upper parts are fairly long gone in decay, especially in the firs (Figure 8). Strangely enough, many of the cedar snags are cut off near ground level and can be easily mistaken for modern stumps. Thick moss and lichen growth on the cut surfaces of the snags indicate that the cutting occurred many years ago. Apparently early inhabitants of the area saw these snags as a source of standing firewood, or, in the case of the cedars, as already seasoned shake bolts. Buried snags can be distinguished from modern snags by their lack of a root swell or buttressing near their base, by the rotting and embayment of the wood right at ground level, and by touch. Run your hand along the trunk and follow it below the ground surface. A snag will keep on going into the ground, but a modern tree rooted at the surface will immediately break up into roots.

The Lost Creek site is in a backwater area where lahars of Old Maid age, flowing down the valley of the Sandy River, ponded in the mouth of Lost Creek valley and actually flowed upstream into the tributary valley for a short distance. As the flows turned the corner to enter the valley, they lost much of their momentum, which explains the lack of abrasion on the snags. Lost Creek itself was probably dammed by the accumulating deposits, forming a small lake (Cameron and Pringle, 1986). The swampy beaver-pond area at the end of the trail in the picnic area may be a remnant of this lake. When Lost Creek finally broke through the barrier, it did so along the boundary between the new deposits and the valley wall, eventually exposing the buried trees now seen in the channel.

The biggest collection of trees in Upper Sandy forest is farther up Old Maid Flat, along the trail between Ramona Falls and the Portage Trail crossing of the Muddy Fork. It is reached by driving another 1¾ mi beyond the Lost Creek turnoff to the end of the road. Much of this section of road is just a track bulldozed on the surface of the Old Maid-age deposits and is very rough. A parking area is at the end of the paved section of road, and a trail parallels the rough portion of the road. Follow the Portage Trail to the northeast to the junction with the Ramona Falls Trail. The trees of the buried forest are found on both sides of the trail for the first half mile toward Ramona Falls. As with the Lost Creek site, these trees were buried by lahars produced during the Old Maid eruptive period. Only one snag has been dated by radiocarbon techniques (Crandell, 1980), and it yielded a date of <250 ybp. Provisional dendrochronologic work by the authors suggests that the main Old Maid-age debris flow swept over Old Maid Flat in the early 1780's A.D.

*Figure 8. Three snags along Lost Creek: one on the near bank and two on the far bank (one short, hollow snag at the water's edge and one tall snag just behind it).*

Another portion of the Upper Sandy buried forest has just recently been discovered, so recently, in fact, that it could not be included on the location map. This portion is on the Clear Fork of the Sandy River, just upstream of where it joins Old Maid Flat. Once again, lahars spreading over the surface of the Flats flooded back upstream on a tributary, burying the forest on the valley floor. In this location, about 40 snags, which are a mixture of Douglas fir and cedar, many over 4 ft in diameter and 20 ft tall, are protruding from the bed of the Clear Fork, indicating that the river is now in a different location from its pre-eruption course.

To reach this area, follow the Old Maid Flat road from the turnoff on Lolo Pass Road. About half a mile down the road is a fork, the right-hand way leading up Old Maid Flat toward Lost Creek and the Ramona Falls trailhead, and the left toward Last Chance Mountain. Take the left fork, which stays up on the valley wall above the level of the Flats. About 1 mi beyond the fork, you will come to the bridge over the Clear Fork with a parking area immediately across the bridge. A fisherman's trail leads up the Clear Fork on the left bank for 200 yd to the start of the snag area. Snags are visible in the river for about a quarter of a mile.

The debris flows that buried these trees filled the channel of the Sandy River (which was probably in the same general location as the modern channel, as determined from deposit thicknesses throughout the valley) and spread over the relatively flat valley floor, covering it from one side to the other. The plant assemblage living on the Flats then was probably very similar to that found there today: large, water-seeking conifers (cedars and Douglas firs) near the edges of the flats and, more importantly, along incised stream channels, and plants more adapted to droughty soil conditions (lodgepole pine) near the center of the valley. When the debris flow swept over the flats, it filled the incised channels, killed the stands of large trees, and swept the smaller lodgepole pines away. The snags seen along the Ramona Falls trail probably mark the path of Ramona Creek and the Muddy Fork of the Sandy River and show that before the Old Maid eruptions, Ramona Creek followed a channel north of its present location and joined the Muddy Fork much farther upstream than it does today.

The snags themselves are impressive; between 30 and 50 are still standing, many of them reaching 100 ft in height and 4 ft in diameter. All of the standing snags at this site are cedar, and there are no cut stumps like those seen father down valley at Lost Creek. No fir or hemlock snags are present either, although fir and hemlock make up the majority of the trees blanketing the valley walls above the effects of the debris flows. Since fir and hemlock do not have the natural decay-resistant properties of cedar, snags of these species have completely rotted away. What remains are cylindrical "wells," the natural casts left in the mudflow deposits after the tree trunks disappeared (Figure 9). They appear as circular holes up to 21 ft deep, sometimes partially overgrown with moss and lichen mats. If you climb down into these wells, you can sometimes see the shape of the swelling base of the tree and even the radiating root pattern at the bottom. This activity is definitely NOT recommended. The deposits are unconsolidated and prone to collapse, and the wells are sometimes narrow and partially filled with loose debris. The direction the debris flow was traveling can also be determined in the wells; larger rocks will be piled on the upstream side of the tree, smaller rocks on the downstream side. The depth of the well is, of course, equal to the depth of the debris flow deposit across the surface of Old Maid Flat plus the depth of the old incised channel of Ramona Creek or the Muddy Fork in which the tree was growing. Again, climbing into the tree wells is definitely NOT recommended. Be content with letting down a tape measure to determine depth. These wells are particularly common near the toe of Yokum Ridge, where the valleys of the Sandy and Muddy Fork come together.

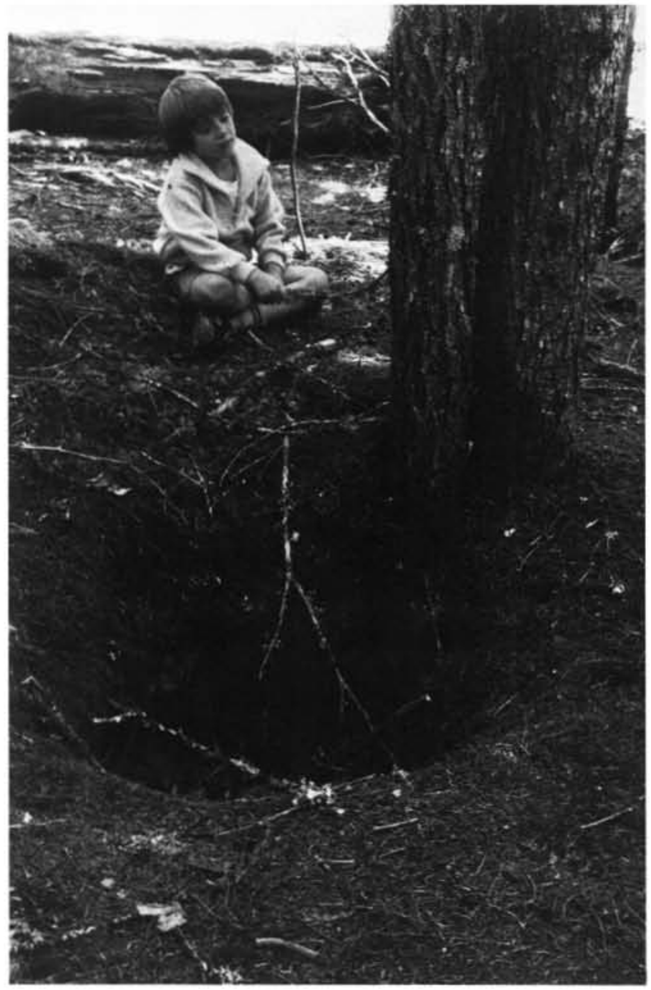


*Figure 9. Typical example of a tree well, this one about 3 ft across and 4 ft deep, located near the Lost Creek picnic area.*

**Tollgate buried forest**

This buried forest is also easy to get to, being located at about the 1,800-ft level along the banks of the Zigzag River adjacent to and upstream from the Tollgate Wayside east of Rhododendron (Figure 10). Most of the snags are on the left bank of the river, which is private property leased from the USDA Forest Service. They can be easily seen, however, from the public land on the right bank. This forest has never been described in the scientific literature and was only recently exposed by erosion when the river shifted its channel during the Christmas flood of 1964 A.D.

About a dozen snags are visible along a quarter-mile reach of the river. Most are less than 5 ft tall and 3 ft in diameter, and apparently all are Douglas fir. The root mat of at least one is visible on the bottom of the river and is polished flat by the erosive action of the water. The trees of this buried forest are being eroded out of the flat expanse of the valley floor by side-cutting of the Zigzag River. None of these trees has been radiometrically dated, but soil profiles, vegetation assemblages, and upstream stratigraphy all indicate that they were buried during the Old Maid eruptive period.

The trees of this buried forest are about the same general size as the Old Maid-age portion of the Twin Bridges buried forest but are considerably smaller than those of the Upper Sandy buried forest on Old Maid Flat. This disparity in size can be explained by the amount of time each forest had to grow before being buried. In the case of the Twin Bridges and Tollgate forests, the trees

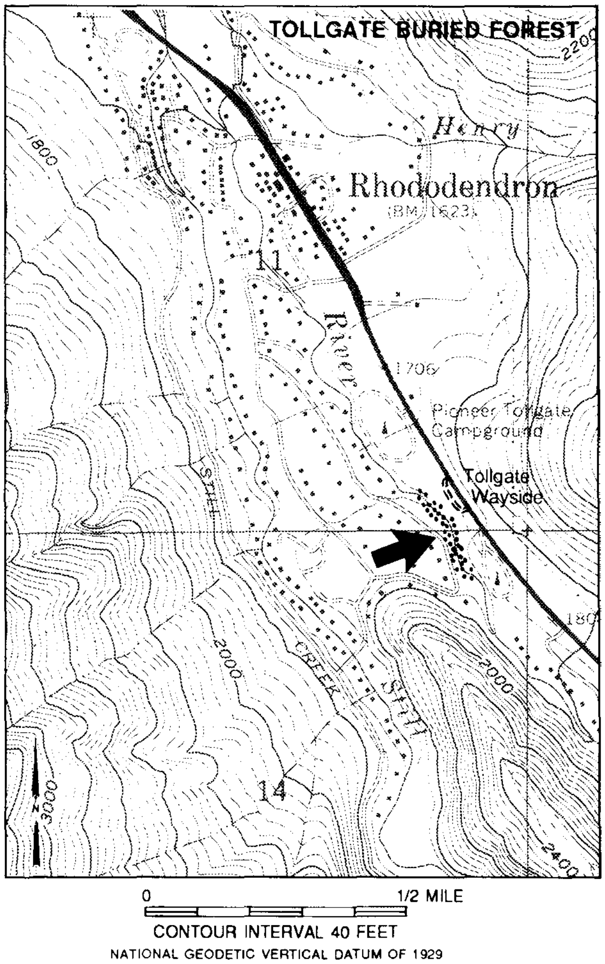



*Figure 10. Location (stippled area) and access map for the Tollgate buried forest. Base is from Rhododendron 7½-minute quadrangle.*

were rooted in debris produced during the Zigzag eruptive period. This creates a time span of about 250 years for the trees to colonize the surface and grow into a forest. In the Upper Sandy forest, the trees were rooted in deposits of the Timberline eruptive period and had at least 1,200 years to develop the old growth assemblage and spacing seen in the pattern of snags and tree wells.

At the start of the Old Maid eruptions, this site was occupied by a young, valley-covering forest composed mostly of Douglas fir. A single large lahar (the same one seen at the top of the cutbank at the Twin Bridges forest) overflowed the channel banks and deposited from 3 to 5 ft of material around the trunks of the trees. The easily decayed firs rotted off at ground level, but the below-ground portions of the trunk, kept constantly saturated by the proximity of the river, were preserved. Channel migration during modern floods has exposed these stumps only over the last 25 years.

### Oxbow buried forest

The downstreammost buried forest of Mount Hood is probably the most difficult to reach. It is located along the banks of the lower Sandy River from Indian John Island to 3 mi below Oxbow County Park at an elevation of 50 to 150 ft (Figure 11). There is no road or trail access; the forest can be reached only by boat. The best example of this forest is located on privately owned land on the left bank downstream from Oxbow Park (the authors had the owner's permission when conducting studies of the deposits in this area). Although thousands of boaters pass by the snags of this forest each year, it has never been mentioned in the scientific or popular literature.

Over a dozen standing snags up to 20 ft tall and 6 ft in diameter are eroding out of 40-ft-high terraces along both banks of the Sandy River about 2 mi upstream from Dabney State Park. There are also two logs extending horizontally over the water for at least 50 ft from the middle of the terrace (Figure 12). Such a position is obviously possible only if the log is in a good state of preservation. All of the trees inspected here were Douglas fir, possessed most of their bark, and showed little or no damage from being buried. This forest was first exposed by erosion accompanying floods in the 1950's (George Casterline, oral communication, 1989). None of these trees have been dated radiometrically, but once again, soil development, vegetation assemblages, weathering depths, and stratigraphic relationships indicate that this forest was buried by material produced during the Old Maid eruptive period.

Exposures of the terrace show that the trees were not buried by a single flow but by a whole sequence of events. A basal unit 2 to 3 ft thick is from a lahar, probably the initial event to fill the river channel and leave deposits in the surrounding forest. The rest of the deposits are more typically fluvial in texture, having numerous thin (1- to 2-ft-thick) units of sand and gravel that are commonly cross-bedded. No soil layers were found between the fluvial units, indicating that all were deposited within a short span of time.

The trees are rooted in an extremely fine-grained, organic-rich layer that is an average of 3 ft above current mean water level. Modern floods generally keep large-diameter Douglas firs from growing within 8 or 10 ft vertically of the water; areas nearer to water level are colonized instead by fast-growing phreatophytes such as cottonwood, alder, and willow. The proximity of the large fir snags to the modern water level suggests that at the time of the Old Maid eruptions the channel of the Sandy River, at least in its lower reaches, was at a somewhat lower level.

The 35 ft of rapidly deposited fluvial material that forms the bulk of the terrace at the Oxbow buried forest exemplifies the complex range of impacts a volcanic eruption can have on downstream environments. At least one primary volcanic flow did travel this far (approximately a 45-mi flow path from the vent area) and is preserved as the basal unit that surrounds the trees. By far the majority of the terrace, however, is composed of secondary fluvial deposits brought down through normal stream processes. Vast quantities of material were deposited in and adjacent to stream channels near Mount Hood by lahars, pyroclastic flows, and sediment-laden stream flow during the Old Maid-age eruptions. This deposition raised the local river base level and created a stream environment of high gradients and loose sediment. This loose sediment was easily eroded and transported downstream, temporarily filling the lower valley as it moved along. Almost immediately, the river started cutting back down through this sediment pile, transporting the eroded sediment to even lower reaches of the valley. The mouth of the Sandy River is occupied by a broad delta, composed, at least in part, of the reworked volcanic debris from upstream.

## SUMMARY

At least three times at six different sites during the post-glacial history of Mount Hood, forests have been overwhelmed and buried by debris from volcanic eruptions. The oldest of these buried forests, the Stadter forest, dates from the Timberline eruptive period 1,800 to 1,400 ybp. This forest was inundated by high-velocity lahars that pushed the trees over and abraded the trunks, removing all of the bark. The next oldest buried forest is the Twin Bridges (lower portion), which was buried by lahars and fluvial deposits

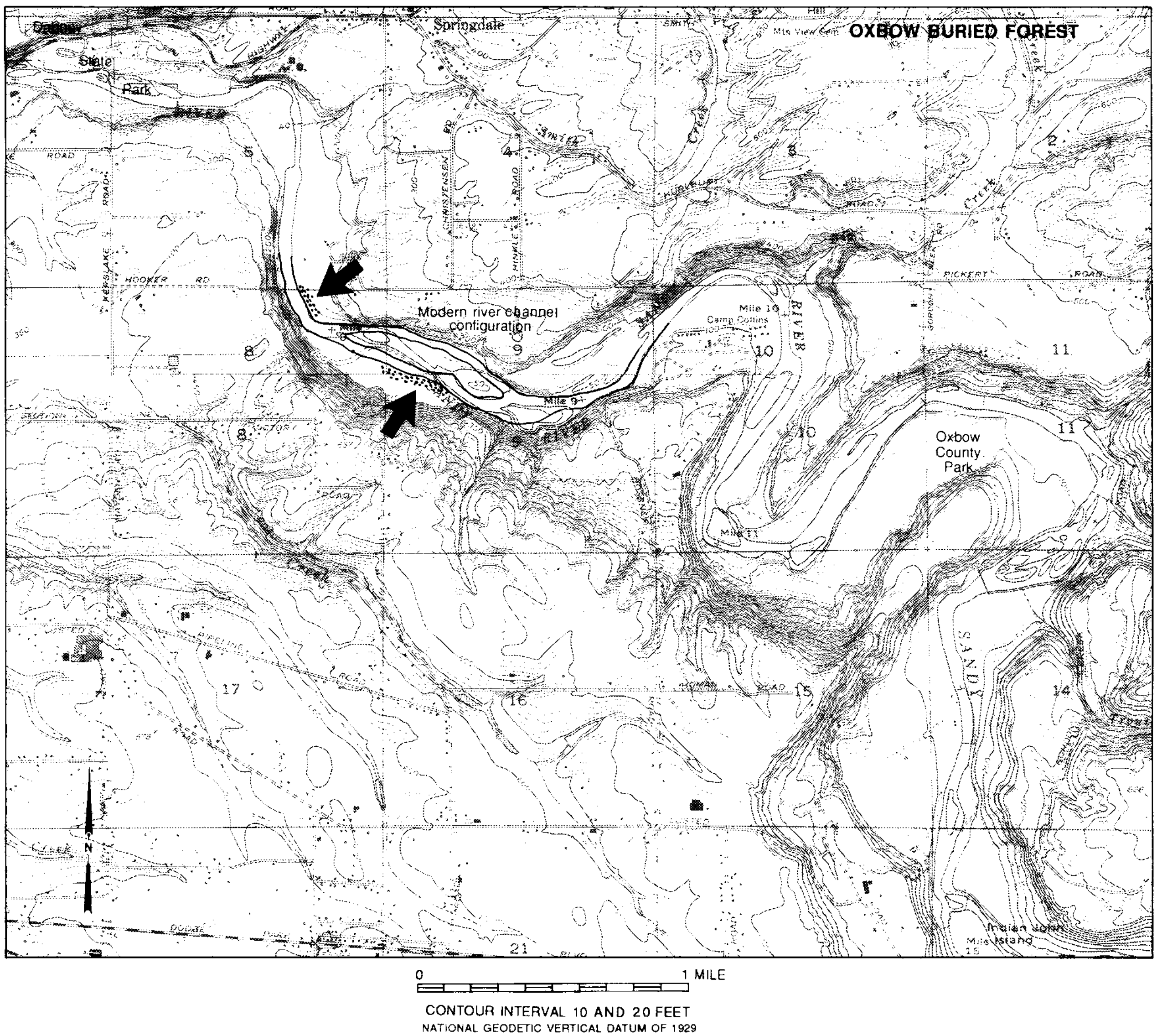



*Figure 11. Location (stippled areas) map for the Oxbow buried forest. Note that the configuration of the present river channel is very different from that shown on available map. Base is from Washougal and Sandy 7½-minute quadrangles.*

of the Zigzag eruptive period, 600 to 400 ybp. These trees are found adjacent to and in the modern channel, indicating that the river, before the onset of the eruption, was located somewhere else in the valley, probably more toward the center.

The other four forests (and the upper half of the Twin Bridges forest) all date from the Old Maid eruptive period, 1760 A.D. to 1810 A.D. Forest conditions ranging from relatively young, closely spaced stands of mostly Douglas fir (such as in the Tollgate forest) to the large, well-spaced cedars and Douglas firs of an old growth forest (as in the uppermost portion of the Upper Sandy forest and in the Oxbow forest) have been preserved by the protecting layers of debris.

Not only do these forests tell us of past ecologic communities, but they graphically display the far-reaching effects of volcanic activity. The valleys of the Sandy, Zigzag, and White Rivers have been filled to depths of many tens of feet as far as 50 mi from the mountain by volcanic events and the subsequent erosion and downstream deposition. Mount Hood last erupted during the time of Lewis and Clark, and there is no reason to believe it will not do so again. These forests give us some idea of what can be expected.

## ACKNOWLEDGMENTS

The authors would like to express deep-felt thanks to Donald B. Lawrence, who shared his samples, notes, photographs, and years of experience with us. We also thank George Casterline for his permission to study and sample the portion of the Oxbow buried forest on his property.

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*Figure 12. Snags of the Oxbow buried forest on the left bank of the Sandy River below Oxbow County Park.*


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## Gresham club displays rocks at Capitol

The Mount Hood Rock Club of Gresham has installed a new exhibit in the display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem. The collection will remain at the Capitol until May 15, 1991. The displayed specimens are from 10 Oregon counties and were provided by 25 adult and six junior members of the club.

Featured in the center of the upper shelf is a three-tiered riser showing more than 30 polished cabochons of different agates—Oregon Sunset, Graveyard Point plume, Carey plume, and ledge agate—and a heart-shaped cabochon of obsidian.

The display of the junior club members includes four operating clocks made with Wascoite, jasper, and thunderegg slabs; Oregon sunstone gem trees, one on a base of petrified oak wood and another on a myrtlewood base; a free-form cabochon of Jefferson County agate; and crystal specimens of stilbite plate and calcite.

The remaining space is taken up by a large sphere of Malheur County jasper; Morrow County opal, rough, polished, and faceted; two limb casts in the form of Owyhee and Biggs jasper scenic slabs; a small mahogany obsidian obelisk; an unusual "fir cone agate" specimen; a large thunderegg slab; two belt buckles; two mounted pendants; a faceted Oregon sunstone; a large round of petrified oak wood; and the name plate of the club fashioned of obsidian.

*—OCRMC news release*

## AGI offers new earth science resource

*Earth Science Investigations*, a new classroom resource has been published by the American Geological Institute (AGI).

Conceived for earth science programs for grades 8-12, this collection of investigations consists of 26 innovative study activities providing the concepts, vocabulary, and worksheets needed to complete them. The following selection of subjects may give a taste of the collection: *What earthquake waves tell us about Earth's interior. - Building a river. - Micro-weather patterns. - Comparing water hardness. - World time-day calculator. - Investigating tides. - Analyzing North American meteorite impact sites.*

The publication is available from the Customer Service Department of AGI, 4220 King Street, Alexandria, VA 22302-1507, for $34.95 per copy plus handling and postage charges of $4 for the first and $1 for each additional copy. For credit-card orders, a FAX number, (703) 379-7563, and two phone numbers, (800) 336-4764 and (703) 379-2480, are available. □

## THESIS ABSTRACTS

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

**ALONG-COAST VARIATIONS OF OREGON BEACH-SAND COMPOSITIONS PRODUCED BY THE MIXING OF SEDIMENTS FROM MULTIPLE SOURCES UNDER A TRANSGRESSING SEA**, by Karen E. Clemens (M.S., Oregon State University, 1987), 75 p.

Heavy-mineral compositions of sands from Oregon beaches, rivers, and sea cliffs have been determined in order to examine the causes of marked along-coast variations in the beach-sand mineralogy. The study area extends southward from the Columbia River to the Coquille River in southern Oregon. The heavy-mineral compositions were determined by standard microscopic identification with additional verification by X-ray diffraction analyses. Initially the beach-sand samples were collected as single grab samples from the mid-beachface, but significant selective sorting of the important heavy minerals prevented reasonable interpretations of the results. Factor analysis of multiple samples from the same beach yielded distinct factors which correspond with known mineral sorting patterns. The effects of local sorting were reduced by the subsequent use of large composite samples, permitting interpretations of along-coast variations in sand compositions. Four principal beach-sand sources are identified by factor analysis: the Columbia River on the north, a Coastal Range volcanic source, sands from the Umpqua River on the south-Oregon coast, and a metamorphic source from the Klamath Mountains of southern Oregon and northern California. The end members identified by factor analysis of the beach sands correspond closely to river-source compositions, the proportions in a specific beach-sand sample depending on its north to south location with respect to those sources. During lowered sea levels of the Late Pleistocene, the Columbia River supplied sand which was dispersed both to the north and south, its content decreasing southward as it mixed with sands from other sources. The distributions of minerals originating in the Klamath Mountains indicate that the net littoral drift was to the north during lowered sea levels. With a rise in sea level the longshore movement of sand was interrupted by headlands such that the Columbia River presently supplies beach sand southward only to the first headland, Tillamook Head. At that headland there is a marked change in mineralogy and in grain rounding with angular, recently supplied sands to the north and rounded sands to the south. The results of this study indicate that the present-day central Oregon coast consists of a series of beaches separated by headlands, the beach-sand compositions in part being relict, reflecting the along-coast mixing at lower sea levels and subsequent isolation by onshore migration of the beaches under the Holocene sea-level transgression. This pattern of relict compositions has been modified during the past several thousand years by some addition of sand to the beaches by sea-cliff erosion and contributions from the rivers draining the nearby Coastal Range.

**DYNAMICS OF INTERMEDIATE-SIZE STREAM BEACH OUTLETS, NORTHERN OREGON COAST**, by Ellen Eberhardt (M.S., Portland State University, 1988), 168 p.

This study measured and evaluated the relation of coastal foredune morphology to stream beach outlets and investigated the processes that are associated with the stream outlet. Intermediate-size streams were studied and defined as those that flow across the beach most of the year but have no tidal influence. Fifty-four of these streams were found along the northern Oregon coast between the Columbia River and Yaquina Bay. Crescent Lake Outlet, Saltair Creek, and Daley Lake Outlet were chosen as study streams for further investigation.

Significant differences at the intermediate-size stream outlets were found in dune morphology and volume, beach profile and plan form, and in wave and wind processes.

Dune height and volume are less at the outlet, especially on the northern side of the stream, because stream wetting of sand was found to interrupt the dominant northward eolian processes. Stream incision into the upper beach allows storm waves to break farther onto the shore, into the area of dune formation. Flooding hazard is also increased by the stream embankment's focusing of wave energy. Increased deposition at stream outlets appears to increase the lower beach elevation in the surf zone and may cause the observed increase in offshore turbulance near the stream. No significant beach sediment size variation was found.

Increased hazard to development is expected because of reduced dune size, lowered beach face, and focusing of storm waves at the stream outlet.

**A GEOCHEMICAL STUDY OF THE EAGLE CREEK FORMATION IN THE COLUMBIA RIVER GORGE, OREGON,** by Rachel A. Carlin (M.S., Portland State University, 1988), 90 p.

The lower Miocene Eagle Creek Formation, a series of volcanic mudflows and debris flows, is exposed in the Columbia River Gorge about 64 km east of Portland, Oregon. By means of instrumental neutron activation analysis, 87 samples were analyzed for trace-element concentrations. Dr. Peter Hooper at Washington State University analyzed 11 samples for major-element chemistry, using X-ray fluorescence. These data were used to determine that the Eagle Creek Formation compositionally ranges from andesite to dacite.

Statistical analysis of the trace-element chemistry showed that, at this point, no lateral correlations or chemical stratigraphy can be determined. However, the use of principal-component analysis and cluster analysis was shown to be very efficient at separating individual mudflow units, thereby making trace-element fingerprinting useful, especially if field relationships are questionable.

A comparison of the Eagle Creek samples with known hydrothermally altered samples from the same formation showed that, on the whole, the bulk compositions of the formation had not been changed, even though secondary clay mineralization is common. Additionally, the upper Eocene to lower Miocene Skamania Volcanic Series was tested as a possible source for the Eagle Creek Formation. The differences in trace-element concentrations and the published ages eliminate this possibility.

Finally, the Eagle Creek Formation was compared to other Miocene Western Cascade rocks. Chemically, all of these rocks follow trends that are probably attributable to andesitic volcanism and tectonic setting. A similar geochemical study of the thicker section of the Eagle Creek Formation on the Washington side of the Columbia River and also a study of the Clackamas River exposures might yet reveal a chemical stratigraphy of the Eagle Creek Formation. The northernmost exposures of the Oligocene-Miocene Little Butte Volcanic Series should also be analyzed as a possible source of the Eagle Creek Formation.

**GEOLOGY AND GEOCHEMISTRY OF THE MAHOGANY HOT SPRINGS GOLD PROSPECT IN THE OWYHEE REGION OF SOUTHEASTERN OREGON,** by Deborah Gilbert (M.S., University of Washington, 1988), 76 p.

Andesitic tuff of the 16.7- to 19.0-m.y.-old Sucker Creek Formation hosts gold mineralization at the Mahogany prospect in southeastern Oregon. The extensive andesitic tuff is the distal deposit of hydroclastic eruptions. It is interbedded with several basalt flows and a discontinuous volcaniclastic sandstone. These are overlain by the tuff of Rockville, which comprises a heterogeneous sequence of rhyolitic air-fall tuffs and water-laid tuffaceous sediments.

The Mahogany prospect hosts mineralization in brecciated portions of the andesitic tuff at the Main fault. Three levels of the mineralized system are exposed. The lowest level hosts gold mineralization and contains quartz-calcite-zeolite veins and stockworks. Above this level is the zone of K-silicate alteration confined to tuffaceous sediments. The uppermost level consists of the eroded remnants of an apron of silicified breccia containing clasts of sinter, other surrounding rock types, and fragments of silicified wood; this breccia was probably erupted from and centered around the Main fault. The area around the Main fault is also characterized by quartz-adularia-pyrite veins and banded quartz-calcite veins. Propylitic and K-silicate alteration are chemically controlled primarily by lithology. Zeolites are zoned around the prospect area, with laumontite in veinlets grading outward to clinoptilolite in the tuff of Rockville. A zone of acid leaching (supergene?) is superimposed on all other alteration types.

Main controls on mineralization were the high permeability of the andesitic tuff and high-angle normal faults trending mainly north-northeast. Anomalous gold values in the explosion breccia and sinter demonstrate the genetic relationship between gold mineralization and the formation of hot springs.

*Lake Owyhee (Oregon Department of Transportation photo)*

**GEOCHEMICAL STRATIGRAPHY OF THE DOOLEY RHYOLITE BRECCIA AND TERTIARY BASALTS IN THE DOOLEY MOUNTAIN QUADRANGLE, OREGON,** by David N. Whitson (M.S., Portland State University, 1988), 122 p.

The Dooley Rhyolite Breccia in northeastern Oregon was erupted between 16 and 12 million years ago from central vents and linear feeder dikes within the Dooley Mountain quadrangle. The peraluminous, high-silica rhyolites of the formation were erupted over an irregular highland of eroded pre-Tertiary metamorphic rocks locally overlain by intracanyon, Eocene Clarno-type basalt flow(s). The Dooley Rhyolite Breccia is exposed in a tectonically disrupted, north-south-trending graven across the Elkhorn Ridge. The formation is variable in thickness, with maximum thickness exceeding 660 m in the south and 600 m in the north half of the quadrangle. Volumetrically, the formation is dominated by block lava flows with lesser associated volcaniclastic and pyroclastic rocks. Although initial and waning phases of eruption of the formation produced ash-flow tuffs that extend well beyond the quadrangle boundaries, volcanism within the quadrangle appears to have been primarily effusive.

At least nine geochemically distinct rhyolite subunits belonging to four related chemical groups have been identified in the formation stratigraphy and appear to represent unique eruptive episodes. Chronologic geochemical patterns within the formation are consistent with a petrogenetic model of repeated partial melting and eruption from multiple silicic magma chambers in an attenuated continental crust.

Basalts correlative with the Powder River Basalt and the Strawberry Volcanics overlie the Dooley Rhyolite Breccia on the north flank of Dooley Mountain. Calc-alkaline basalts correlative with the Strawberry Volcanics are overlain by tholeiitic basalts of uncertain affinity on the south flank of the mountain. These basalt flows on respective flanks of the mountain were not continuous across the quadrangle. Rhyolitic volcanism in the Dooley Mountain quadrangle is contemporary with the Strawberry Volcanics and the Picture Gorge Basalt of the Columbia River Basalt Group.

**GEOLOGY OF THE STOCKADE MOUNTAIN 15-MINUTE QUADRANGLE, MALHEUR AND HARNEY COUNTIES, OREGON,** by John P. Stimac (M.S., Fort Hayes State University, 1988), 79 p.

The Stockade Mountain 15-minute Quadrangle lies in Harney and Malheur Counties of southeastern Oregon. The study area has twelve mappable units that range in age from early Miocene to Recent and are mostly volcanic or lacustrine in origin.

The oldest unit is an early Miocene unnamed igneous complex composed of basaltic and andesitic flows. This unit forms the basement rock in the region and is unconformably overlain by the early to middle Miocene Littlefield Rhyolite. The Littlefield Rhyolite is a laterally extensive unit that had more than one point of origin. Faulting along the eastern flank of Stockade Mountain has exposed the most extensive section of the rhyolite. The middle Miocene Juntura Formation, a lacustrine unit, unconformably overlies the rhyolite. During deposition of the Juntura Formation, the Wildcat Creek Ash-Flow Tuff was erupted. Volcanic activity in the Harney Basin to the west produced the very extensive, upper Miocene Devine Canyon Ash-flow Tuff, which separates the Juntura Formation and the overlying upper Miocene Drewsey Formation, also a lacustrine unit. At approximately the same time that the Devine Canyon Ash-flow Tuff was erupted, an unnamed basalt southwest of Crowley was also erupted from an area to the south of the study area. The unnamed brown volcanic siltstone at Roger's Valley indicates a period of continued erosion of previous units and deposition of the siltstone. The unconformable upper Miocene Drinkwater Basalt is a prominent ledge-former in the area. The youngest basalt found within the area is an unnamed one at Buck Mountain. This pile of basalts flowed into the area from the north or northwest. Quaternary colluvium, alluvium, and playa deposits are the youngest units that are present. Structurally, the area is dominated by the Basin and Range tectonics, but the juxtaposition of the Owyhee Plateau has complicated the structures, stratigraphy, and correlation of the units. □

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(**Flora**, *continued from page 33)*

Stanley, G.D., Jr., 1986, Late Triassic coelenterate faunas of western Idaho and northeastern Oregon: Implications for biostratigraphy and paleogeography, *in* Vallier, T.L., and Brooks, H.C., eds., Geology of the Blue Mountains Region of Oregon, Idaho, and Washington: U.S. Geological Survey Professional Paper 1435, p. 23-40.

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White, J.D.L., White, D.L., Vallier, T.L., Stanley, G.D., and Ash, S.R., in preparation, Intra-arc deposits within the Wallowa Terrane, Pittsburg Landing area, Oregon and Idaho; complex "basin" history elucidated by sedimentary and fossil evidence. □

## MINERAL EXPLORATION ACTIVITY

### MAJOR MINERAL-EXPLORATION ACTIVITY

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| Baker 1990 | Baboon Creek Chemstar Lime, Inc. | T. 19 S. R. 38 E. | Lime-stone | App |
| Baker 1990 | Cracker Creek Mine Simplot Resources, Inc. | T. 8 S. R. 37 E. | Gold | App |
| Crook 1988 | Bear Creek Freeport McMoRan Gold Company | Tps. 18, 19 S. R. 18 E. | Gold | Expl |
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| Grant 1983 | Susanville Kappes Cassiday and Associates | Tps. 9, 10 S. Rs. 32, 33 E. | Gold | Expl |
| Harney 1990 | Pine Creek Battle Mountain Exploration | T. 20 S. R. 34 E. | Gold | Expl |
| Josephine 1990 | Martha Property Cambiex USA, Inc. | T. 33 S. R. 5 W. | Gold | App |
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| Malheur 1988 | Grassy Mountain Atlas Precious Metals, Inc. | T. 22 S. R. 44 E. | Gold | Expl, com |
| Malheur 1988 | Jessie Page Chevron Resources Company | T. 25 S. R. 43 E. | Gold | Expl |
| Malheur 1988 | Kerby Malheur Mining | T. 15 S. R. 45 E. | Gold | Expl, com |
| Malheur 1990 | Ali/Alk Atlas Precious Metals, Inc. | T. 17 S. R. 45 E. | Gold | App |
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| Malheur 1990 | Racey Project Billiton Minerals USA | T. 13 S. R. 41 E. | Gold | Expl |
| Malheur 1990 | Lava Project Battle Mountain Exploration | T. 29 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Freezeout Western Mining Corporation | T. 23 S. R. 42 E. | Gold | Expl |
| Malheur 1990 | Calavera NERCO Exploration Company | T. 21 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Cow Valley Butte Cambiex USA, Inc. | T. 14 S. R. 40 E. | Gold | Expl |
| Malheur 1990 | Mahogany Project Chevron Resources Company | T. 26 S. R. 46 E. | Gold | App |

MAJOR MINERAL-EXPLORATION ACTIVITY (continued)

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Malheur 1909 | Snake Flat Atlas Precious Metals, Inc. | T. 22 S. R. 44 E. | Gold | App |
| Malheur 1990 | Stockade Mountain BHP-Utah International | T. 26 S. Rs. 38, 39 E. | Gold | Expl |
| Malheur 1990 | Goldfinger Site Noranda Exploration | T. 25 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Buck Gulch Teague Mineral Products | T. 23 S. R. 46 E. | Ben-tonite | Expl |
| Malheur 1990 | Sand Hollow Noranda Exploration | T. 24 S. R. 43 E. | Gold | Expl |
| Malheur 1990 | South Star Claims Carlin Gold Company, Inc. | T. 25 S. R. 39 E. | Gold, silver | App |
| Malheur 1990 | KRB Placer Dome U.S., Inc. | T. 25 S. R. 43 E. | Gold | App |
| Malheur 1990 | Stockade Project Phelps Dodge Mining Company | Tps. 25, 26 S. R. 38 E. | Gold | App |
| Marion 1990 | Bornite Project Plexus Resources Corporation | T. 8 S. R. 3 E. | Copper | App |

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued.

**Status changes**

During November and December, three new applications for exploration permits were received. The decrease in application rate was expected as most of the active projects were brought into the permitting program and as activity slowed for the winter.

Early in February, Atlas Precious Metals notified the department that they were considering taking a bulk sample from their Grassy Mountain Project. An adit and decline would need to be constructed for this project.

Questions or comments about exploration activities in Oregon should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office, 1534 SE Queen Avenue, Albany OR 97321, telephone (503) 967-2039. □

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

## Cover photo

This view of an area at Hancock Field Station shows red paleosols on a clayey slope above a ridge of conglomerates and sandstone of the middle Eocene "nut beds" of the Clarno Formation.

Hancock Field Station, operated as a natural-history camp by the Oregon Museum of Science and Industry, Portland, is within the Clarno Unit of the John Day Fossil Beds National Monument in Wasco County, Oregon. It is a major point of interest in the field trip guide beginning on the next page.

## Twilight fireball reported

*by Richard N. Pugh and Nathan Stratton, Cleveland High School, Portland*

A large fireball occurred over northern Oregon and southern Washington on January 21, 1991, at 5:26 p.m. (1726 PST; January 22, 1991, 0126 Greenwich Mean Time). It entered the atmosphere over Gresham, Multnomah County, Oregon (about 45.5° N., 122.7° W.), and moved roughly northeast at a 30° angle of descent to its end point near Narrowneck Gap, Yakima County, Washington (45.5° N., 121.1° W.). The event lasted at least five seconds.

The limits of reported observations (all in Oregon) were as follows: North, The Dalles, Wasco County (44.5° N., 122.3° W.); South, Madras, Jefferson County (44.5° N., 122.3° W.); and West, Tigard, Washington County (45.5° N., 122.6° W.). Eleven persons reported this fireball, the second author being one of them.

Most observers reported that the object was as bright as a full moon, brightening as it fell, and was approximately the moon's apparent size. Its shape was reported as oval to round with a long, yellow-green-white tail that was emitting "sparks." Almost all colors were reported seen in the head of the fireball, most commonly green and white. The fireball flared brightly near the end of its path and divided into four smaller fireballs that followed each other in a train and then faded out. No sounds or shadows were reported. However, the fireball was bright enough to backlight the few clouds present in the sky.

Even though the sun had set at the time, it was still daylight. Therefore, the object should be considered a daylight fireball.

At present, there is no evidence that any meteorites were produced in the event. Usually, several fireballs are reported over Oregon each month and one or two daylight fireballs each year. Of this number, 5-10 percent will produce sonic booms, indicating that meteorites made it to the ground.

The sightings of this fireball were reported to the Global Volcanism Network, Smithsonian Institution, and published in the *Bulletin of the Global Volcanism Network*, v. 16, no. 1 (January 31, 1991), p. 13-14. Anyone with any additional information about this event or other fireball sightings should contact Dick Pugh, Cleveland High School, 3400 SE 26th Avenue, Portland, OR 97202, phone (503) 280-5120. □

## Financial assistance for geologic studies in Washington available

Awards to help defray expenses will be available in the 1992 fiscal year for original geologic mapping and other geologic studies useful to the Washington Division of Geology and Earth Resources (DGER) in compiling the new geologic map of Washington.

Available funds will be approximately $15,000 for fiscal year 1992, and awards will be made on the basis of proposals submitted. The individual awards are expected to range approximately from $500 to $2,500. First priority will be given to proposals for work in areas lying within the northwest and southeast quadrants of the new state geologic map, specifically areas that are currently unmapped, poorly mapped, or poorly understood geologically.

Deadline for the submission of proposals is June 3, 1991. Copies of the request for proposals are available through geoscience department chairpersons. The editors of *Oregon Geology* also have a copy of the request for proposals on file.

These quadrants of the state geologic map are scheduled for completion by 1995 and 1993, respectively.

For more information and suggestions, contact J. Eric Schuster, Department of Natural Resources, Division of Geology and Earth Resources, Mail Stop PY-12, Olympia, WA 98504, phone (206) 459-6372 or SCAN 585-6372. *—DGER news release*

# A field guide to mid-Tertiary paleosols and paleoclimatic changes in the high desert of central Oregon—Part 1

*by Gregory J. Retallack, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403*

This field trip guide was prepared for the Theme Meeting of SEPM (Society for Sedimentary Geology) to be held August 15-18, 1991, in Portland, Oregon. The theme of this meeting is "Continental margins—sedimentation, tectonics, eustasy, and climate." Part 1 of this paper presents the introduction and the guide for the first day of the two-day field trip. Part 2, the guide for the second day and the conclusion of the paper, including the list of references, will be published in the following (July 1991) issue of *Oregon Geology*. *—Editor*

**ABSTRACT**

Colorful badlands of the high desert of north-central Oregon have long been known for their plant and animal fossils of Tertiary geological age. Fossil soils (paleosols) in these sequences account in part for the scenic interbedding of red, green, and orange claystone, and also are allowing reassessment of Tertiary paleoenvironments. The transition from steamy jungles of the Eocene to the sagebrush desert of today is recorded in the change from deeply weathered, red, kaolinitic clayey paleosols of the Eocene, to the red, brown, and green smectitic paleosols of the Oligocene, to the thin, brown calcareous paleosols of the Miocene, and to the gray, silty calcareous paleosols of the Quaternary. Episodic paleoclimatic deterioration evident from this sequence of paleosols can be related to stepwise global cooling and marine regression. These global effects were exacerbated locally by accretion of the Oregon Coast Range and by volcanic construction of the Western Cascades. Both barriers to westerly storms cast a rain shadow over central Oregon, so that it has become drier as well as cooler and more continental in climate during Neogene time.

**INTRODUCTION**

The high desert of Wheeler and Jefferson Counties in north-central Oregon is now widely associated with the name of John Day, after whom the main river of the region was named. He passed through this area in 1812 with the Overland Expedition of the Pacific Fur Company. This bleak scenic landscape is one of climatic extremes, often covered with snow in winter but hot and dry in summer. Mean annual temperature for Antelope is 8 °C, with January mean of -1 °C and August mean of 19 °C (Ruffner, 1978). Due to low rainfall (mean of 320 mm annually in Antelope), it supports desert scrub of sage and juniper, and a colorful volcanic and alluvial sequence of Tertiary geological age crops out well (Figure 1). In contrast to the present vegetation, fossil plants of Eocene age, now well known from several localities near Clarno, indicate a climate much wetter, warmer and more equable than at present, more like that of modern lowland Panama (Manchester, 1981). The transition from steamy jungles of the past to the open ranges of today is recorded in a copious fossil record of plants, nonmarine snails, freshwater fish, reptiles, and mammals in this

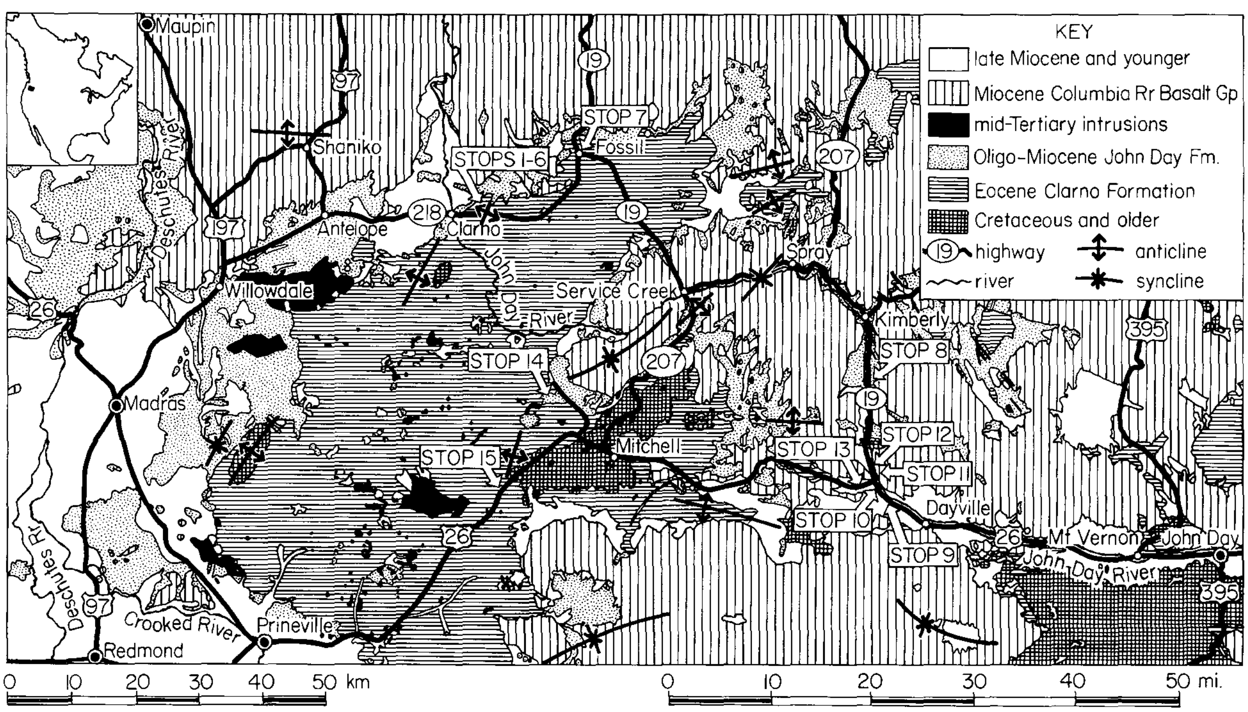



*Figure 1. Simplified geology and excursion stops in the John Day country of north-central Oregon (adapted from Walker, 1977).*

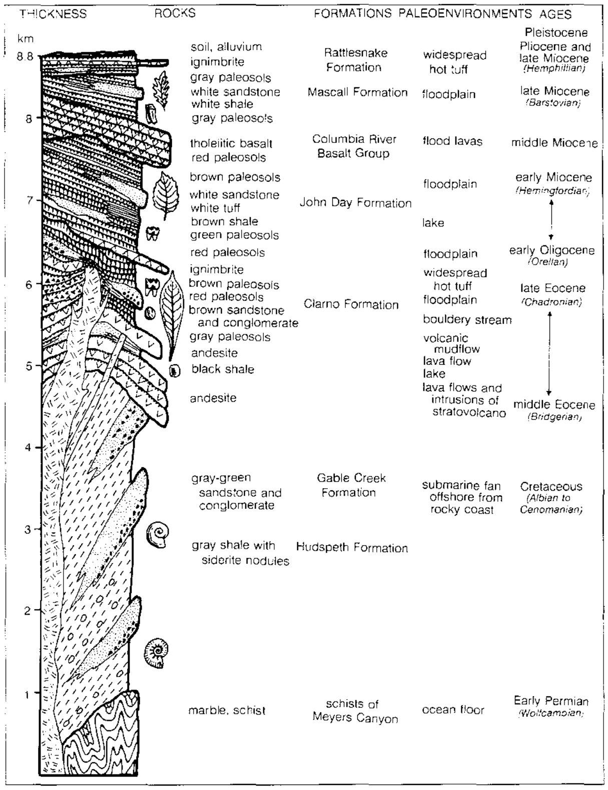



*Figure 2. A composite stratigraphic column for central Oregon (from Oles and others, 1973; Swisher and Prothero, 1990).*

region (Merriam and Sinclair, 1907; Merriam and others, 1925; Chaney, 1948; Downs, 1956; Manchester, 1981; Wolfe, 1981b; Ashwill, 1983; Rensberger, 1983; Manchester and Meyer, 1987). These profound paleoenvironmental changes also are reflected in a sequence of paleosols ranging in age from middle Eocene to the present. In contrast to more than a century of investigation of the region's fossil riches, scientific study of its paleosols is just beginning (Fisher, 1964; Retallack, 1981, 1985; Pratt, 1988; G.S. Smith, 1988). This excursion explores the potential for paleopedological studies and their implications for understanding paleoenvironmental changes in north-central Oregon over the past 45 million years (m.y.).

The oldest rock units in the region are highly deformed schists of Permian age (Figure 2). These are overlain by a thick sequence of Cretaceous marine rocks, formerly considered deltaic (Oles and others, 1973). Later study of these sediments and their foraminifera concluded that the sediments formed in a submarine fan complex (Kleinhans and others, 1984). An isolated exposure of Early Cretaceous conglomerates that occurs at Goose Rock north of Picture Gorge (Aguirre and Fisk, 1987), probably was deposited in braided streams or a fan delta.

These basement rocks are intruded and overlain by andesitic volcanic and alluvial rocks of the Clarno Formation, which ranges in age from middle to late Eocene, some 54 to 37 m.y. old (McKee, 1970; Rogers and Novitsky-Evans, 1977; Manchester, 1981; Vance, 1988; Walker and Robinson, 1990). Volcanic plugs, lava flows, and lahars of the formation are indications of accumulation in and around a chain of andesitic volcanic cones. During Eocene time, before development of the modern Cascades or the Oregon Coast Range, this part of Oregon was much closer to the coast than it is today (Figure 3). The lower part of the Clarno Formation includes lacustrine deposits with fossil fish (Cavender, 1968; Lundberg, 1975) and leaves (Hergert, 1961). Some of these plant-bearing beds in northeastern Oregon near Heppner and Pilot Rock (outside the area of this excursion) are more likely of Paleocene age and may be better placed in a separate unit underlying the Clarno Formation (Elmendorf and Fisk, 1978; Gordon, 1985; Walker and Robinson, 1990). Near the middle of the Clarno Formation are the well-known "nut beds," which have yielded fossil fruits, seeds, leaves, wood, and rare vertebrate fossils compatible with a middle Eocene age (or Bridgerian land mammal "age") and a warm, wet, tropical paleoclimate (Manchester, 1981; Pratt, 1988). Also compatible with such a paleoenvironment are red, highly weathered fossil soils (Retallack, 1981; G.S. Smith, 1988) associated with the "nut beds." In the upper part of the formation are some fossil plants of tropical affinities (McKee, 1970) but also a number of decidedly more temperate forms (Manchester, 1986). Fossil vertebrates at this level are very different from the archaic forest faunas of the North American middle Eocene, and more like later Eocene (Chadronian land mammal "age" as redated by Swisher and Prothero, 1990) faunas of more open country (McKenna *in* Evernden and others, 1964; Hanson, 1989). Moreover, fossil soils associated with these vertebrates provide evidence of disturbed streamside grassland and woodland less dense than earlier during Eocene time (Retallack, 1985; Pratt, 1988). Thick, red paleosols of kinds formed under forest are common along the unconformity between the Clarno and John Day Formations (Fisher, 1964).

Rhyolitic ash-flow tuff and dacitic to rhyodacitic air-fall tuffs are conspicuous in latest Eocene, Oligocene, and early Miocene (22- to 37-million-year-old) John Day Formation (Woodburne and Robinson, 1977; Robinson and others, 1990). These alluvial and lacustrine deposits were well supplied with volcanic ash from the present area of the Western Cascades to the west (Robinson and others, 1984). This volcanic arc active during Oligocene time was far to the west of the Eocene Clarno volcanic arc (Figure 3). The John Day Formation has been divided into nine units (A to I) in the basin to the northwest of the ridge formed by the old Clarno arc (Robinson and others, 1984), but to the southeast there are four distinctly colored members (Fisher and Rensberger, 1972). The basal red part of the John Day Formation consists of a succession of noncalcareous and oxidized woodland paleosols, in which neither fossil plants nor vertebrates were preserved. Local lake deposits in this part of the formation contain abundant fossil leaves, and sometimes also fossil fish (Cavender, 1969) and insects (Cockerell, 1927; Peterson, 1964). The fossil leaves are mainly deciduous temperate angiosperms together with the dawn redwood (*Metasequoia occidentalis*). Fragmentary and rare vertebrate fossils from this stratigraphic level are compatible with, but not compelling evidence for, an early Oligocene age (Orellan or Whitneyan land mammal "age"). The middle green and buff member of the John Day Formation is well known for its abundant and diverse vertebrate faunas (of the early Arikareean land mammal "age"; Merriam and Sinclair, 1907; Fremd, 1988). In tooth and limb design, these faunas were better adapted to open country than their Eocene antecedents (Webb, 1977); but they were not nearly so well adapted to former open vegetation, indicated by associated fossil soils, as are modern faunas of wooded grassland. The uppermost yellow and white member of the John Day Formation also contains abundant fossil mammals (of the late Arikareean and Hemingfordian land mammal "ages"), and its fossil soils are evidence of drier climate and wooded grassland vegetation (Retallack, 1985). Few fossil lake deposits or fossil leaves have been found in these early Miocene rocks. An especially well developed fossil soil occurs at the very top of the formation capping a landscape of moderate relief.

Covering this ancient landscape are extensive flows of the Columbia River Basalt Group. Most of these were erupted during middle Miocene time (13 to 17 m.y. ago; Tolan and others, 1984; Hooper and Swanson, 1990). Individual flows of these flood basalts had volumes of 10 to 30 $km^3$, but some flows are known to have exceeded 600 $km^3$ in volume. Eruption of such a large flow is thought to have lasted from several days to weeks. Many of them were erupted from fissures in northeastern Oregon, eastern Washington, and western Idaho and flowed all the way out to the Pacific Ocean near Portland. In the John Day region of north-central Oregon, however, the Columbia River basalts were more local in origin. Some flows of the Picture Gorge Basalt at the base of the Columbia River Basalt Group along the John Day River between Dayville and Spray can be traced back to a swarm of dikes near Monument and Kimberly (Figure 1). To the west around Madras, the lowest Columbia River Basalt Group flows are of the Prineville chemical type and geologically younger than the Picture Gorge Basalt. They were probably erupted from vents now buried near Powell Buttes to the south (G.A. Smith, 1986).

Sediments overlying the Picture Gorge Basalt and interbedded with later flows of the Columbia River Basalt Group are referred to as the Mascall Formation. These volcaniclastic sediments contain a mammalian fauna of middle Miocene age (Barstovian land mammal "age"; Downs, 1956). The Mascall Formation represents a major stream system draining the older Mesozoic and Paleozoic rocks of the Blue Mountains to the south. Much of its sediment load consisted of volcanic ash from the ancestral Cascade volcanoes to the west. Fossil leaves of cool-temperate deciduous angiosperms and conifers dominate lacustrine deposits of the Mascall Formation (Chaney, 1948), whereas its vertebrate fauna of camel, horse, and pronghorn antelope indicates grassy woodland or wooded grassland (Downs, 1956). Fossil soils in the formation are additional evidence for dry, open vegetation apparent from the structure of fossil mammalian teeth and limbs. If there were closed-canopy woodlands at that time, they were restricted to stream margins and lake shores.

Overlying and interbedded with Columbia River Basalt Group rocks in a small area of the valley of the Deschutes River near Gateway, north of Madras, are alluvial clays and sandstones of the Simtustus Formation (G.A. Smith, 1986). What little is known about its fossil plants (Pelton flora of Ashwill, 1983) and paleosols conveys an impression of paleoenvironments similar to that for the Mascall Formation, with which it was at one time identified.

Disconformably overlying the Mascall Formation in most of north-central Oregon is the Rattlesnake Formation, which includes local fanglomerates and alluvial sandstones and claystones as well as a thick rhyodacitic ash-flow tuff (Oles and others, 1973). This widespread ash-flow tuff is thought to have erupted from a vent in the Harney Basin south of Burns. Other parts of the formation represent ancestral drainages of the John Day and Crooked Rivers, which continued to receive ash from the ancestral Cascades to the west. Fossil mammals of the Rattlesnake Formation are of late Miocene age (Hemphillian land mammal "age") and include a markedly more modern fauna of grazing horses and pronghorn antelope (Merriam and others, 1925). Its fossil flora also is more modern and includes elm, sycamore, and willow (Chaney, 1948). This vegetation of deciduous angiosperm trees may be contrasted with open grassy vegetation apparent from fossil soils and vertebrates in the Rattlesnake Formation.

Coeval with deposition of the Rattlesnake Formation to the east, the region around Madras received enormous amounts of basalt, tuff, and gravel of the Deschutes Formation during a period of late Miocene and early Pliocene active volcanism (G.A. Smith, 1987). The source volcanoes are no longer exposed, because they subsided in a large graben along the current Cascade crest. This graben has been filled by the Pliocene-Pleistocene basaltic shield volcanoes as well as the prominent stratovolcanoes of Mount Jefferson, Three Fingered Jack, Mount Washington, and the Three Sisters. Fossil plants (Ashwill, 1983), fish (Cavender and Miller, 1972), mammals (Downs, 1956, Gateway locality), and paleosols (G.A. Smith, 1987) of the Deschutes Formation are similar to those of the Rattlesnake Formation and indicate a semiarid, cool climate approaching the one found in this high-desert region today.

Much remains to be done to learn more about the details of climatic change recorded in this fossiliferous Tertiary sequence, but the causes of climatic change must be sought beyond this region. Climatic drying may have been caused by reorientation of continental subduction with accretion of the Oregon Coast Range (Engebretson and others, 1985). During Eocene time, this region was dotted with andesitic volcanoes closer to the coast than now. By Oligocene time, this volcanic arc had reformed in the present area of the Western Cascades, and it began to cast a rain shadow over the John Day region (Figure 3). This climatic drying would have been exacerbated by the increased continentality and by profound marine regression at the Eocene-Oligocene boundary (Haq and others, 1987). These changes could also have been responsible for the climatic cooling observed. Other possible causes for cooling at about this time are the thermal

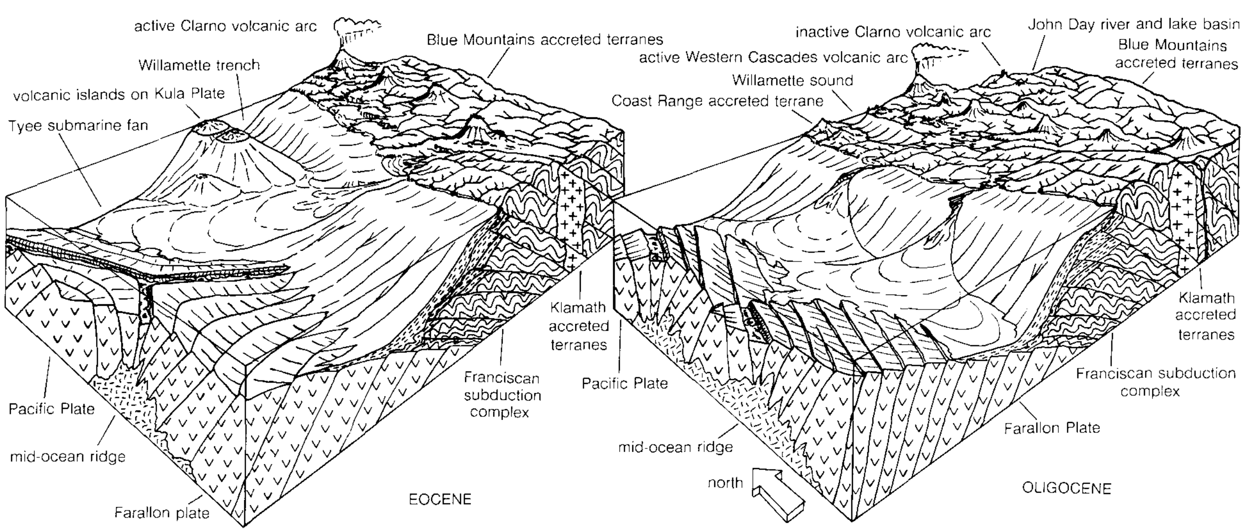



*Figure 3. Paleogeographic cartoons of the Pacific Northwest during Eocene (left) contrasted with Oligocene time (right), illustrating a rearrangement of oceanic plates and volcanic arcs with accretion of the Oregon Coast Range. These events predated Miocene spreading of the Basin and Range and volcanic activity of the High Cascades (adapted from Engebretson and others, 1985).*

isolation of Antarctica by a surrounding ocean current following the rifting away of Australia (Kennett, 1982); impact of extraterrestrial bodies, which left a strewn field of tektites in rocks of about this age in the United States Gulf Coast (Glass and others, 1979); and reduced atmospheric carbon dioxide and its diminished greenhouse effect because of reduced Neogene rates of subduction and volcanism (Creber and Chaloner, 1985). The Eocene-to-Oligocene transition was prominent among a number of Neogene climatic deteriorations, as the world slipped from a regime of middle Eocene maximal expansion of tropical climate toward the ice ages of the past few million years.

**EXCURSION ITINERARY FOR FIRST DAY**

This two-day excursion originates and ends in Madras, Jefferson County, Oregon. Madras is built on the Pliocene Deschutes Formation, which forms an extensive plateau to the north and west. U.S. Highway 97, heading north from Madras, provides excellent views of surrounding peaks. Hills to the east of the plains are faulted ash-flow tuffs and sedimentary rocks of the Oligocene-Miocene John Day Formation. Grizzly Mountain to the southeast is a rhyolitic dome of the John Day Formation. Gray Butte, west of Grizzly Mountain, is mainly John Day Formation, but exposes also some underlying rocks of the Eocene Clarno Formation. Round Butte farther west is a late Pliocene basaltic shield volcano. Pleistocene composite volcanoes of the High Cascades are visible on the skyline to the west. From south to north these include multiple peaks of the Three Sisters, the rock spire of Mount Washington, eroded towers of Three Fingered Jack, and the cone of Mount Jefferson.

A road cut 10 mi north of Madras on U.S. Highway 97 toward The Dalles exposes the contact between the Deschutes Formation and the underlying Columbia River Basalt Group. A mile farther north on the ridge top to the east of the road is a Pleistocene intracanyon flow. This flow erupted from a small shield volcano east of Madras and flowed down ancestral Hay Creek toward the Deschutes River. Hay Creek has since cut a new valley parallel to the flow (Oles and others, 1973). Another mile farther north, we see tuffaceous claystones of the upper John Day Formation (Unit I of Robinson and others, 1984), and a red paleosol separating it from the overlying Yakima Basalt of the Columbia River Basalt Group.

Turn east from U.S. Highway 97, 17 mi north of Madras, onto Oregon Highway 218 toward Antelope. Yakima Basalt shows excellent columnar jointing 3 mi east of this junction. Some 5 mi east is a prominent ledge of ash-flow tuff within the upper John Day Formation (Unit H of Robinson and others, 1984). At 6 mi east of the junction is another ash-flow tuff (Unit G) and at 7 mi east an alkali olivine basalt flow (Unit F) of the John Day Formation. These Oligocene basalts are associated with dikes of local vents and are compositionally distinct from tholeiitic flood lavas of the Columbia River Basalt Group. At 9 mi east of the junction of Highways 97 and 218 in the cut south of the road is another ash-flow tuff of the John Day Formation (Unit E). The abundance of thick ash-flow tuffs and basalts is characteristic of the western facies of the John Day Formation, which filled a topographic basin between the Western Cascades and the moribund Eocene Clarno volcanic arc (Robinson and others, 1984).

At the small town of Antelope, turn southeast, continuing on Oregon Highway 218 toward Clarno. Trachyandesite of the lower John Day Formation (Unit B) is exposed in a road cut 1.5 mi southeast of Antelope. Continue east along Highway 218, past the unsealed road to the south that leads to Ashwood and via Muddy Road to the abandoned commune of Rajneeshpuram. From that turnoff, Highway 218 climbs to a pass that affords excellent views of the valley of the John Day River to the east. The cliffs north of the pass consist of tuffs (Unit F) and a welded tuff (Unit G) of the upper John Day Formation. These are capped by the Columbia River Basalt Group on the skyline. These middle Miocene flood basalts also cap Iron Mountain in the distance to the east across the river. The white, tan, green, and red John Day Formation crops out in scattered badlands along the river, but its contact with overlying flood basalts is obscured in places by slumping. Dark red, orange, and gray sediments and lava flows of the Clarno Formation crop out extensively to the southeast past the bridge across the John Day River. The higher peaks farther south are capped by Columbia River basalt overlying the John Day Formation.

Clarno was the site of a ferry, later replaced by a bridge, across the John Day River. It now consists of a few farmhouses and a grange hall. In the hills north of Highway 218, 1 mi east of the bridge, the basal ash-flow tuff of the John Day Formation can be seen overlying red claystones of the upper Clarno Formation. These tuffaceous claystones immediately under the ash-flow tuff yielded a radiometric (K-Ar) age of 32.8 m.y. (Evernden and James, 1964, corrected by method of Dalrymple, 1979). This date is anomalously young and is regarded as suspect (Woodburne and Robinson, 1977). Massive volcanic rocks farther southeast are andesitic lava flows of the lower Clarno Formation.

Access to Hancock Field Station is by a gravel road that turns off north at a point 2.5 mi east of the bridge across the John Day River. This facility is within the Clarno Unit of John Day Fossil Beds National Monument, and is run as a natural-history camp by the Oregon Museum of Science and Industry in Portland. Inquiries and permission to visit should be obtained from the caretaker living there: Joseph Jones, telephone (503) 763-4691.

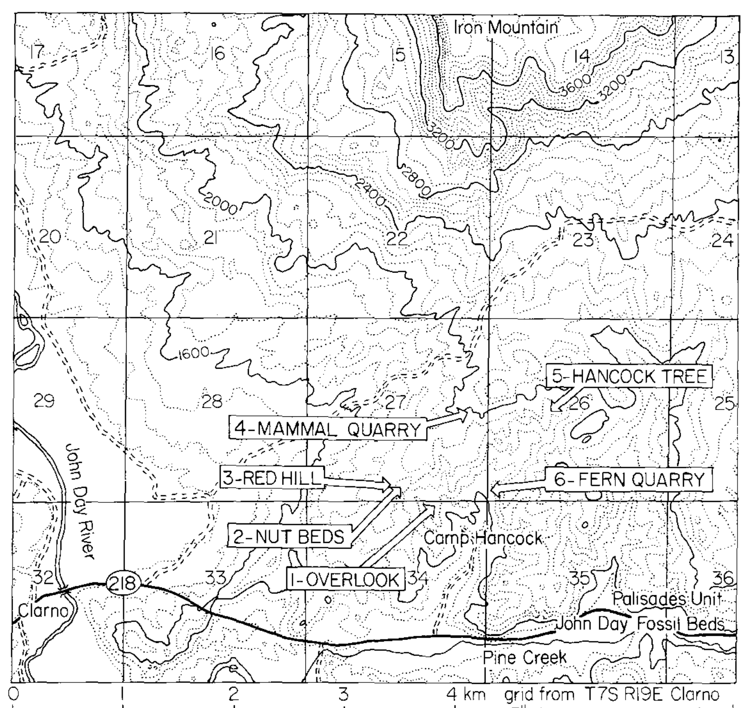



*Figure 4. Excursion stops on a walking tour of the principal fossil localities around Hancock Field Station near Clarno, Oregon.*

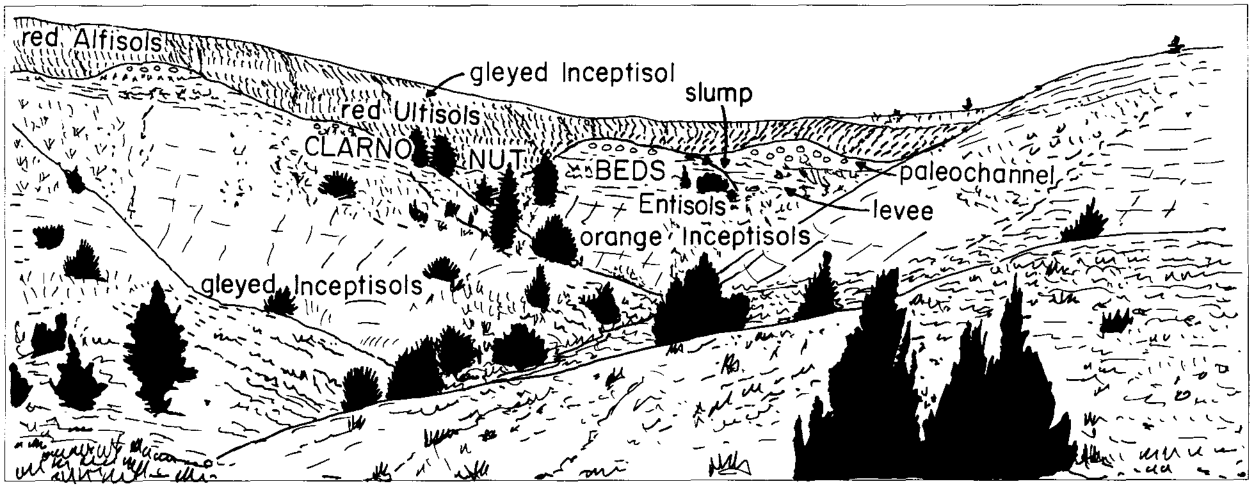



*Figure 5. Geological sketch of facies associated with the Clarno "nut beds," viewed from the east.*

Park the vehicles at the lower parking lot and prepare for a walking tour of at least three hours (Figure 4). Walk west up into the camp and then northwest past the A-frame huts and away from "Berrie Hall," a large enclosed dining area. A footpath leads uphill from the northeastern huts out of the camp.

**STOP 1. "Nut beds" overlook, Hancock Field Station**

Some 300 m west of Camp Hancock, on the crest of a low ridge, is an excellent view (Figure 5) of middle Eocene alluvial rocks of the Clarno Formation (NW¼NE¼ sec. 34, T. 7 S., R. 19 E., Clarno 15-minute Quadrangle). The prominent bluffs of sandstone and conglomerate are the Clarno "nut beds", a well-known fossil locality for leaves, fruits, seeds, wood, and mammals. From here, the "nut beds" can be seen to be lenticular in outline and sandwiched between red claystones of the hill on the skyline and variegated red, green, and orange claystones of the gullies below. The lenticular shape of the "nut beds" is obscured somewhat by slumping, especially of the central bluff. These coarse-grained sedimentary rocks represent sandy levees and conglomeratic channels of a meandering stream that flowed through clayey soils now preserved in the varicolored badlands. Some of the paleosols were waterlogged, for example, the gray-green ones below the "nut beds" and the two gray bands in the red hillside above. Most of the paleosols, however, were freely drained and have been highly oxidized to orange and red colors. Blocky outcrops at the top of the red badlands are the basal welded tuff of the John Day Formation.

**En route**

Continue west downhill toward the "nut beds" and through the gate in the barbed-wire fence. The white powder prominent during summer months in the dry clayey washes here is mirabilite ($Na_2SO_4 \cdot 10H_2O$; J. Pecor, personal communication, 1982). It forms by evaporation of ground water flowing off the plant-bearing andesitic conglomerates and smectitic claystones of the badlands immediately to the west. Mirabilite rather than anhydrous sodium sulfate (threnardite) is favored at temperatures of <32 °C in the laboratory, and <16 °C in nature (Wells, 1923). Probably, mirabilite forms here following evaporation of winter rain and persists for much of the nearly rainless summers of this region.

Also seen near the gate is a dike of porphyritic andesite about 1 m wide dipping at 66° to the west and striking northeast (azimuth 068°) to intersect a large andesitic intrusion forming the ridge 200 m in that direction.

The nature of surface soils on these badland slopes can be seen along the trail. As in many badland regions in dry parts of the western United States, these soils are weakly developed (Torriorthents of U.S. Department of Agriculture, 1975). Their surface horizon (some 10 to 20 cm thick) is cracked, with irregular blocky ("popcorn") ped structure. Below that (extending to some 40 cm) is a zone of carbonate powder and flattened, zoned crystals of gypsum and calcite within cracks in the rock. Most of the weathering observed in these claystones dates back to Eocene time, when these paleosols formed soils of floodplains. In order to properly understand Eocene soil formation, it is necessary to dig a meter or so into fresh bedrock, beyond the overprint of the thin surface soil.

**STOP 2 Clarno "nut beds," Hancock Field Station**

The "nut beds" of the Eocene Clarno Formation are interbedded sandstones and siltstones with a cap of massive conglomerate, 0.5 mi northeast of Camp Hancock (SW¼SE¼ sec. 27, T. 7 S., R. 19 E., Clarno 15-minute Quadrangle). The conglomerate forming the top of the bluffs contains principally boulders and pebbles of porphyritic andesite, which have conspicuous phenocrysts of zoned plagioclase. Sorting, roundness, and imbrication of the clasts are poor. The matrix to the conglomerates includes clay, silt, sand, and plant debris—all cemented by multiple generations of chalcedony with local calcite and zeolites. Large voids and copiously branched veins within the conglomerate are filled with chalcedony. These sediments and their uniquely preserved fossils, may have been altered by hot spring activity, perhaps associated with intrusion of the nearby andesitic dikes and plug. The interbedded sandstones and siltstones underlying the conglomerates also are silicified in places, and show a variety of small-scale sedimentary structures, including ripples and scour-and-fill. Some of these small erosional features are steep sided and may be footprints of large mammals. The conglomeratic facies is typical for paleochannels of streams in mountainous regions, and the interbedded sandstones and siltstones may represent point bar and levee deposits of a stream on the seaward slope of a large coastal andesitic volcanic arc (Figure 3).

Fossil fruits and seeds, the "nuts" after which these beds are informally named, are found throughout the sequence. Most of the large fruit and seed collection made by the late Thomas Bones (Bones, 1979) came from the basal unit of the upper conglomerate. Over the past several years, Steven Manchester has systematically excavated a layer low in the underlying sequence of sandstones and siltstones. A cherty siltstone bed there contains fossil fruits, seeds, leaves, and wood—an uncommon occurrence for a plant fossil locality, offering the promise of allowing reconstruction of complete fossil plants from their different organs. About 100 genera of fruits and seeds, 80 of leaves and 40 permineralized woods had been recognized in the "nut beds" (Bones, 1979; Manchester, 1981, 1986). Common among these are fruits of walnuts(*Juglans clarnensis*), moonseed (*Chandlera lacunosa*), icanica vine (*Palaeophytocrene foveolata*), dogwood (*Langtonia*), palm (*Palmocarpon*), and leaves of aguacatilla (*Meliosma*). Modern relatives of most of these plants are restricted to vegetation of moist, equable tropical regions, such as lowland Panama and Taiwan. In addition, modern relatives of many of the fossils are vines and epiphytes, from which it can be inferred that the fossil flora was a rain forest community with several distinct tiers. It is possible that the climatic preferences of these plants have changed through time, but paleoclimate also can be reconstructed from adaptive features of plants that presumably reflect fundamental aspects of plant physiology. A warm paleoclimate is indicated for the Clarno "nut beds" because many of the leaves are large and most (60 percent) are entire margined. Some seasonality is suggested by growth rings in fossil wood. Presumably this was due to a dry rather than cool season, because Wolfe (1978) envisages climate with a mean annual temperature of 21° to 25 °C and a mean annual range of temperature of only 3° to 7 °C for Eocene floras of the nearby Puget Group in southwestern Washington.

Fossil mammals have been recovered from the base of the conglomerate in the southernmost outcrop of the "nut beds." The fauna is still under study by C.B. Hanson (personal communication, 1990), but includes crocodile, turtle (*Hadrianus), small browsing horse (Orohippus major*), small cursorial rhinoceros (*Hyrachyus eximius*), brontothere (*Telmatherium*), and creodont carnivore (*Patriofelis ferox*). These creatures are typical of middle Eocene faunas (Bridgerian land mammal "age") and of forest communities elsewhere in western North America. This assessment of geological age is confirmed by K-Ar estimates of 43.7 and 43.6 m.y. for pumice layers in the "nut beds" (Vance, 1988).

Paleosols in the "nut beds" are weakly developed (Psamments and Fluvents). They are recognized principally by the presence of fossil root traces, because they contain few other indications of soil formation and much relict bedding. Especially conspicuous are thickets of scouring rushes (*Equisetum clarnoi*) fossilized erect and in place of growth in several of these streamside paleosols (Retallack, 1981). These paleosols indicate frequent disturbance by flooding along stream banks.

**En route**

Continue uphill west from the "nut beds" to the area of past excavations into the central gray band high on the red badlands slopes.

**STOP 3. "Red hill", Hancock Field Station**

Red claystones overlying the "nut beds" on the hill to the west contain numerous strongly developed paleosols of the Eocene Clarno Formation (SE¼SW¼ sec. 27, T. 7 S., R. 19 E., Clarno 15-minute Quadrangle). The thick (2.4 m), gray (Munsell hue 5Y) band in the center of the slope includes a weakly developed, seasonally waterlogged paleosol (gleyed Inceptisol). Relict bedding is conspicuous in most of the profile, but is less apparent in a surficial dark-gray (A) horizon. A diffuse subsurface horizon (Bg) contains blocky peds defined by purple-black mangans. Underlying this is brick-red (hue 10R) paleosol of a kind more typical of those excavated in the rest of the trench on this hill (G.S. Smith, 1988). These are thick (1.8 m), moderately developed profiles (Ultisols below this red paleosol and Alfisols above and including it). A drab silty surface horizon (A) and scattered drab-haloed root traces pass down into a clayey subsurface horizon (Bt) with blocky structure and scattered small (3-4 mm diameter) ferruginous concretions.

The green discoloration of the surface horizon and root traces within the paleosols may be due to burial gleization around remnant organic matter, and their brick-red color may in part be due to burial dehydration of ferric hydroxides that were originally reddish brown in color. Slickensides along the faces of former soil clods and reduction in thickness due to burial compaction also are likely. These kinds of alteration are common among paleosols (Retallack, 1990, 1991). Although they compromise some interpretations of these paleosols, much evidence of former soil formation remains.

Paleoclimatic indications from these paleosols are well in accord with evidence from fossil plants and animals in the "nut beds" below. These paleosols are noncalcareous throughout and have deep and copious root traces and burrows, as is typical of tropical forested soils in humid climates. The red paleosol below the drab profile and other red profiles to the top of the hill have up to 94 volume percent of mainly smectitic clays and a ratio of alkalies and alkaline earths to alumina of 0.26 to 0.29. By comparison, other red paleosols between these and the "nut beds" below have up to 98 volume percent of mainly kaolinitic clay, with less abundant smectite, and base-to-alumina ratios of 0.18 to 0.17 (G.S. Smith, 1988). There was thus a pronounced paleoclimatic change during accumulation of the paleosol sequence in this hill, from wetter to somewhat drier but still generally humid climate. There may also have been a shift to greater climatic seasonality, because complex ferric concretions become more abundant in paleosols higher up in the hill.

The paleosols also offer evidence of past landscapes and their history. The drab and manganiferous paleosols may have escaped oxidation in areas of periodically high water table. The brick-red ones have shown patterns of redistribution of iron around root traces in recent microprobe studies (G.S. Smith, 1988), unlike near-constant amounts of total iron found around drab root haloes presumed to have formed entirely after burial (Retallack, 1983, 1990, 1991). There may have been, during soil formation, some chemical reduction and mobilization of iron (gleization) in clay around roots in these formerly well-drained paleosols as well. Thus both red and gray paleosols formed in low-lying floodplains. The parent materials for all these soils were gravelly andesitic debris, as for the soils of the "nut beds." The more thorough weathering to red claystone in some of these paleosols indicates periods of landscape stability and soil formation on the order of tens of thousands of years.

**En route**

Walk along the red badlands slope to the north toward a saddle between the Clarno "nut beds" and the cliffed hill to the west. The cliffs and large blocks littering the slope are the basal ash-flow tuff of the John Day Formation. This is probably the material K-Ar dated at 35.7 m.y. (from Evernden and James, 1964, corrected by method of Dalrymple, 1979) and mistakenly thought to be from the Clarno "nut beds." More recent fission track ages on this welded tuff are 36.8 and 37.4 m.y. (Vance, 1988), which is late Eocene (Swisher and Prothero, 1990).

Continue on foot trails toward a broad marshy area traversed by a rough jeep track. From the saddle overlooking this low area can be seen a flat spur held up by an andesite flow within the upper Clarno Formation. This flow is separated by additional sediments from the eroded top of a large intrusion of andesite forming a ridge closer to Hancock Field Station. The location also offers good views to the north of the basal ash-flow tuff of the John Day Formation on a low ridge. Above that are red, then brown and green, then white badlands of the John Day Formation below a thick sequence of Columbia River Basalt Group flows that cap Iron Mountain on the skyline.

Continue along the jeep trail over a low rise and to a quarry into brown claystones and conglomerates.

**STOP 4. Clarno "mammal quarry," Hancock Field Station**

The "mammal quarry" in the upper Clarno Formation is about 1 mi north from the "nut beds" (SE¼NE¼ sec. 27, T. 7 S., R. 19 E., Clarno 15-minute Quadrangle). These clayey rocks underlie the basal ash-flow tuff of the John Day Formation, but their orange and brown color contrasts with brick-red badlands above the "nut beds." This sequence is a different alluvial facies that accumulated in an erosional landscape developed on top of the "nut beds" and overlying red beds. The floor of the quarry represents a conglomeratic channel deposit with clasts that consist mainly of porphyritic andesite. The walls of the quarry have been re-excavated recently, and reveal levee deposits of silt and clay with numerous paleosols (Pratt, 1988).

A few fossil fruits and seeds have been found in paleochannel deposits here (McKee, 1970). These were identified with better known forms from the nearby Clarno "nut beds" and include walnut (*Juglans clarnensis*), moonseed (*Odontocaryoidea nodulosa* and *Diploclisia*), icanica vine (*Palaeophytocrene* cf. *P. foveolata*) and grape (*Vitis* and *Tetrastigma*). These remains are anomalous compared to fossil mammals and paleosols here, which indicates paleoenvironmental change during the late Eocene as compared with middle Eocene.

Mammal fossils were first discovered here in 1956 by Lon Hancock, an amateur paleontologist from Portland. Between 1956 and 1959, Hancock, Arnold Shotwell, and Malcolm McKenna developed a large collection of vertebrates, most of it now in the Condon Collection at the University of Oregon. The bones are preserved disarticulated and cracked, within clumps that each include few kinds of animals. They appear to have accumulated on the point bar of a stream, as carcasses that rotted and disarticulated in place (Pratt, 1988). Taxonomic work continues on these remains (Mellett, 1969; Hanson, 1973, 1989, personal communication, 1990; Pratt, 1988; Schoch, 1989), which include fish, crocodile (*Pristichampsus*), rodent, anthracothere (*Heptacodon*), rhinoceros (*Teletaceras radinskyi* and *Procadurcodon*), brontothere (*Protitanops*), tapir (*Plesiocolopirus hancocki* and *Protapirus*), agriochoere (*Diplobunops*), horse (*Epihippus gracilis* and *Haplohippus texanus*), creodont carnivore (*Hemipsalodon grandis*), and saber-tooth cat (Nimravinae). These mammals show closest affinities with late Eocene faunas (Chadronian land mammal "age" as redated by Swisher and Prothero, 1990) elsewhere in North America. At more than 38 m.y. old, this is the oldest known fossil fauna of Chadronian type. These faunas show a slight modernization in tooth height and in limb proportions for more open country than found in archaic Eocene forest faunas. For many years it has been thought that Chadronian faunas evolved in open-country refugia in Asia and migrated across the Bering land bridge during late Eocene time to displace older forest faunas of North America (Webb, 1977). The rhinos, tapir, and brontothere are similar to Japanese, Korean, and Siberian Eocene mammals, but the other mammals are North American endemic forms (Hanson, personal communication, 1990). Isolated intermontane basins in the western United States, such as the one represented by this "mammal quarry," could have been important to the evolution of these distinctive faunas that later became widespread in the rest of North America (Retallack, 1985).

Several kinds of paleosols have been recognized in the "mammal quarry" above the conglomeratic layer bearing fossil mammals, fruits, and seeds (Pratt, 1988). They are thin (20-30 cm), olive-colored, weakly calcareous, and with large root traces and much relict bedding (Fluvents). They contain prominent black horizons and septarian nodules rich in manganese. Above these is a thick (1 m), weakly developed, orange-yellow paleosol (Inceptisol) with abundant surficial, very fine root traces preserved by chalcedony (A horizon) and with a subsurface zone of clay enrichment (Bt or incipient argillic horizon).

Such weakly developed paleosols cannot be considered compelling evidence for paleoclimate, but their weakly calcareous composition compared to comparably developed noncalcareous paleosols lower in the Clarno Formation may indicate a somewhat drier climate than earlier in the Eocene. These paleosols contain large root traces of a size formed under trees, as well as abundant very fine root traces, and they probably supported early successional, riparian, grassy woodland. These paleosols are associated with stream deposits, but there is no sign of coal, gray-green clay, pyrite, or other indications of permanent waterlogging. The manganiferous zones may have been placic horizons of soils in locally wet zones of streamsides, but the generally orange hue of the paleosols and deep penetration of root traces are indications of good drainage. These paleosols probably flanked a steep, upland, gravelly stream. Parent materials of the paleosols were andesitic gravelly alluvium. Relict bedding is conspicuous in these paleosols, which each represent only a few hundreds to thousands of years of soil formation.

Paleosols and fossil mammals of the "mammal quarry" are evidence of drier and less dense forest vegetation during late compared with middle Eocene, but there is little evidence of this from the fossil plant remains here. The plant fossils are not silicified like those of the "nut beds" and were in a separate drainage—and so probably were not redeposited after erosion from the "nut beds." Instead, these fossils may represent relict stands of wet forests and are perhaps comparable to those relict species from Miocene rain forests that persist today in well-watered gullies of eastern Australia (Beadle, 1981).

**En route**

Walk northeast around the hill at about the same elevation below cliffs of the basal ash-flow tuff of the John Day Formation. Continue 400 m into the headwaters of a deep gully with extensive exposures of lahars of the upper Clarno Formation and into a narrow canyon draining south.

Hills to the north and east consist of a poorly exposed sequence of olive claystones and white ash similar to that exposed in the "mammal quarry." These are overlain by an andesite flow of the upper Clarno Formation also seen along the way between "Red hill" and the "mammal quarry." A thick red paleosol developed on sediments overlying this flow is the same ancient land surface described elsewhere by Fisher (1964).

**STOP 5. Clarno "Hancock tree," Hancock Field Station**

The "Hancock tree" is a conspicuous permineralized trunk near the entrance of a small gully extending north from Hancock Canyon, about 2.5 mi northeast of Camp Hancock (SE¼NW¼ sec. 26, T. 7 S., R. 19 E., Clarno 15-minute Quadrangle). Additional fossil trunks and stumps have been excavated from the base of a volcanic mudflow or lahar (a widely used Indonesian term for such deposits) higher in the gully. This locality lies within the Clarno Formation, at a stratigraphic level below the "mammal quarry," and is probably of middle Eocene age.

The thick (11 m) lahar contains jumbled angular clasts of porphyritic andesite that were extensively zeolitized and weathered during late Eocene time. Phenocrysts in the andesite clasts include hornblende and plagioclase. The silty matrix of the lahar also includes scattered granules of zoned plagioclase. The lahar was preceded by a thin (20 cm) traction deposit, similar to those attributed to hyperconcentrated flow preceding lahars (G.A.Smith, 1987). Neither this flood of water nor the lahar itself succeeded in dislodging all the trees. Although very close to their volcanic source, these mudflows were slowing down out on the flanks of a volcano.

The "Hancock tree" (Do not deface or sample!) has been identified as similar to the katsura (*Cercidiphyllum japonicum*) of China and Japan. The soil on which it grew is preserved under the lahar, along with its leaf litter (Retallack, 1981). The paleosol is moderately thick (30 cm) and weakly developed (Inceptisol), with a light-colored, sandy near-surface horizon (E) and an orange, weakly ferruginized, and slightly clayey subsurface horizon (Bw), over weakly calcareous sandstone (C). Its leaf litter includes both leaves and fruits of extinct plants allied to sycamore (*Macginitea angustiloba*) and katsura (*Joffrea speirsii*), plants of cool-temperate climatic and early successional affinities (Crane and Stockey, 1985; Manchester, 1986). The fossil leaf litter also contains a variety of other leaves, including those of fan palms, that today are intolerant of frost. This leaf litter probably represents vegetation early in ecological succession to colonize areas disturbed by lahars and associated hyperconcentrated flow close to the volcano.

These inferences from the fossil flora can be compared with those from the paleosol. The profile is weakly calcareous at depth and probably formed in a subhumid-to-humid climate, more like that revealed by paleosols in the "mammal quarry" than those associated with the "nut beds." Differentiation of a weakly ferruginized subsurface zone (Bw) is compatible with woodland vegetation, evident from its fossil leaf litter and trunks. This paleosol formed on flood deposits in the lower regions of hummocky topography and alluvial outwash flanking andesitic volcanoes of a kind comparable with those of the present Cascade Range. Parent materials of the soil were sandy and gravelly alluvium and lahars of andesitic composition. Time for formation of this paleosol was not long, considering its weak development, lacking a subsurface horizon that would qualify as spodic or argillic. Nevertheless, there was some leaching of carbonate and remobilization of iron and clay. The paleosol represents a hiatus of several hundred to a few thousand years, enough for plant succession and growth of the observed crop of tree trunks.

Along the path north of the "Hancock tree" is the midden of a packrat (*Neotoma* spp.) with well-preserved plant fragments of middle Holocene age (W.G. Spaulding, personal communication, 1985). These rodents collect vegetation for their nests and for food, and the plant fragments are preserved by their pungent urine. With radiometric dating to establish their age, packrat middens can provide a detailed picture of Pleistocene changes in vegetation of arid regions (Spaulding and others, 1983).

### En route

Continue down the gully past the "Hancock tree" and into the main valley of Hancock Canyon. A footpath follows the dry creek bed south toward Hancock Field Station and past a small stock pond. At a point between this stock pond and a second one farther down the valley, the long scar of a quarry into white rocks can be seen on the hillside, 200 m above and to the west of the canyon floor. Scramble up to this outcrop.

### STOP 6. Clarno "fern quarry," Hancock Field Station

The "fern quarry" is a prominent excavation on a hill 0.3 mi northeast of Camp Hancock (SW¼SW¼ sec. 26, T. 7 S., R. 19 E., Clarno 15-minute Quadrangle). It is a long excavation into plant-bearing white volcanic ash of the upper Clarno Formation, at a stratigraphic level above lahars and the "Hancock tree," but below the "mammal quarry." Radiometric dating to 43 m.y. old (Vance, 1988) indicates that these leaf beds are middle Eocene in age like the "nut beds."

One-half meter above the base of the excavation is a layer rich in fossil plant remains, principally roots and rhizomes but occasionally with recognizable plant remains (here identified by the author): mostly horsetails (*Equisetum clarnoi*), bird's nest fern (*Salpichlaena anceps*), and tree fern (*Hemitelia pinnata*), as well as rare angiosperm leaves (of kinds traditionally identified as "*Ficus plinerva*" and "*Cryptocarya eocenica*"; Hergert, 1961). These remains represent the leaf litter of early successional vegetation on a thin (10 cm), weakly developed paleosol (Fluvent). This vegetation was more advanced in ecological succession than that of the thickets of *Equisetum* seen in the "nut beds" (Stop 2) but is not as advanced as woodlands preserved around the "Hancock tree" (Stop 6). Comparable colonization of volcanic ash by ferns has been observed around El Chichon, an active volcano in Mexico (Burnham and Spicer, 1986).

### En route

Descend into Hancock Canyon and continue south along the foot trail past the southern stock pond to Hancock Field Station and the vehicles. This is the conclusion of the walking tour.

After reboarding the vehicles, head back out to Oregon Highway 218 and proceed east toward Fossil. Lahars of the upper Clarno Formation are well exposed in the Palisades, a line of cliffs north of the highway 1 mi east of Hancock Field Station, near the rest area and marked trails of the Clarno Unit of John Day Fossil Beds National Monument. These are the same lahars of presumed middle Eocene age seen in Hancock Canyon (Stop 5). Here they have weathered into hoodoos: narrow pillars protected from erosion by more weather-resistant clasts of the lahar. High on the hills to the north of this point is an andesite flow of the uppermost Clarno Formation and above that, on the skyline, is the basal ash-flow tuff of the John Day Formation.

Additional lahars and andesitic flows of the Clarno Formation are exposed along the highway as it climbs into the headwaters of Pine Creek. From Pine Creek summit and on the long descent toward Fossil, the Columbia River Basalt Group can be seen overlying the John Day Formation.

Continue across Highway 19 into downtown Fossil, turning east and then north to Wheeler County High School at the foot of the hill on the north side of town.

### STOP 7. John Day leaf beds, Fossil

In the bank north of the playing fields behind Wheeler County High School in Fossil (SW¼NW¼ sec. 33, T. 6 S., R. 21 E., Fossil North 7½-minute Quadrangle) light brown shales of the lower John Day Formation yield numerous fossil leaves and rare insects, fish, and salamanders. These fossil remains are similar to the "Bridge Creek flora" and similar fossil floras at numerous localities in central Oregon (Wolfe, 1981a). The most common fossils are foliar spurs of dawn redwood (*Metasequoia occidentalis*), a genus of deciduous conifer that has survived in the wild only in remote regions of China (Chaney, 1948). This is a diverse fossil flora (Manchester and Meyer, 1987; Wolfe and Tanai, 1987), but the following species are especially common: Alder (*Alnus hollandiana*), a hornbeamlike dicot (*Paracarpinus chaneyi*), maple (*Acer osmonti*), and an exinct dicot (*Pteleaecarpum oregonensis*). Also found are fossil beetles, flies, cases of caddis flies (Trichoptera: ichnogenus *Folindusia*), mudminnow fish (*Novumbra oregonensis* Cavender, 1969), salamanders (*Taricha lindoei* Naylor, 1979), and a tooth of an unidentified bat (Brown, 1959).

The fossil plants are evidence of a substantially cooler climate than existed during deposition of the Clarno Formation (Chaney, 1948). *Metasequoia* in today's China (Bartholomew and others, 1983), grows in regions of moderately high summer rainfall (averaging 1,280 mm annually) that are cool and seasonal (January mean of 1.7 °C and August mean of 22 °C). Other elements of the flora also show cool-temperate affinities and were part of an extinct kind of mixed mesophytic forest that was widespread in the Pacific Northwest. Modern comparisons and foliar physiognomy of this fossil flora can be considered evidence that mean annual temperature was 3° to 11 °C, with a mean cold-month temperature of -2° to 1 °C, and mean warm-month temperature of 20° to 27 °C (Manchester and Meyer, 1987).

These deposits are varved in places and, with their fossil fish, were clearly deposited in lakes. Such lacustrine deposits can be contrasted with massive claystones that yield terrestrial mammal fossils elsewhere in the John Day Formation and are sequences of paleosols in alluvial floodplain sequences. Revisions of an original lacustrine interpretation have occurred at one time or another for many of the fossiliferous sequences of Tertiary age in the western United States (Gregory, 1969). While there are some clearly lacustrine deposits, such as parts of the Eocene Green River Formation of Wyoming, many mammal-bearing Tertiary deposits are now recognized to be floodplain deposits, including numerous paleosols.

**En route**

Return south through Fossil to Oregon Highway 19 and turn east toward Spray and Kimberly. Up the hill east of Fossil we see numerous exposures of andesite flows of the Clarno Formation. This is the main axis of the Clarno volcanic arc, which was a topographic ridge trending northeast and separating the western from eastern depositional basins of the John Day Formation (Robinson and others, 1984). The eastern facies consists of air-fall volcanic ash variably modified by streams, lakes, and soils and has fewer thick ash-flow tuffs and basalt flows than the western facies.

Over the summit past Shelton State Park, the road descends into the valley of the John Day River and runs upsection through the eastern limb of the broad, northeast-trending Fossil anticline. Red beds and tuffs of the John Day Formation crop out 14 mi southeast of Fossil. Near Service Creek, the gorge of the John Day River is flanked by cliffs of the Picture Gorge Basalt flows of the Columbia River Basalt Group.

Continue following Highway 19 through Service Creek and toward Spray (rather than turning south on 207 toward Mitchell). The John Day Formation crops out by the road again in the core of the broad Spray anticline centered on the small town of Spray. There is a thick, red paleosol at the contact between John Day Formation and Picture Gorge Basalt in road cuts here.

Near Kimberly, continue south on Highway 19 (rather than turning east on 207). About 3 mi south of Kimberly, a conspicuous wall of Columbia River basalt is visible to the west across the John Day River. This dike is about 8 m wide and can be traced northwest (azimuth 325) for 5 mi. This dike and a swarm of similar dikes farther east near the town of Monument are thought to have been feeders of the Picture Gorge Basalt flows.

Turn into the Foree unit of the John Day Fossil Beds National Monument, signposted at a turnoff leading east, 8.5 mi south of Kimberly. Leave the vehicles in the parking area and walk east 200 m along the nature trail into the badlands.

**STOP 8. John Day mammal beds, Foree**

The most accessible outcrops by the nature trail in the Foree area of the John Day Fossil Beds National Monument (Sec. 32, T. 10 S., R. 26 E., Picture Gorge 15-minute Quadrangle) are green tuffs and tuffaceous claystones deposited by streams and locally altered by ancient soil formation. This is in the middle part of the John Day Formation, at a higher stratigraphic level than the lake beds behind Fossil School (Stop 7). The prominent weather-resistant stratigraphic marker bed high in the cliffs is an ash-flow tuff in the middle John Day Formation.

The Foree area exposes the same fossiliferous deposits found to the south in Turtle Cove, where Thomas Condon discovered fossil vertebrates as early as 1869. Many fossils collected between 1870 and 1877 were sent to O.C. Marsh at Yale University and provided valuable evidence for, among other things, the Tertiary evolution of horses (Clark, 1989). Around the turn of the century, collections also were made by field parties from the University of California at Berkeley (Merriam and Sinclair, 1907). Collecting continues from the University of Washington (Rensberger, 1983) and the John Day Fossil Beds National Monument (Fremd, 1988). This is a very diverse fauna of more than 100 species (Merriam and Sinclair, 1907; T. Fremd, personal communication, 1991), including turtle (*Stylemys capax*), deerlike chevrotain (*Hypertragulus hesperius*), oreodon (*Eporeodon occidentalis*), rhinoceros (*Diceratherium armatum*), three-toed horse (*Miohippus anceps*), dog (*Mesocyon josephi*) and saber-tooth cat (*Nimravus debilis*). Also found here are land snails (*Polygyra dalli*) and pits of hackberry (*Celtis willistoni*). The faunas of the green, middle John Day Formation are late Oligocene in age (early Arikareean land mammal "age"). Their great diversity and range of adaptations for locomotion and feeding but lack of high-crowned teeth or elongate cursorial limbs can be interpreted as indications of former woodland vegetation (Van Valkenburgh, 1985; Prothero, 1985).

A variety of paleosols have been found in the John Day Formation. Those of the Foree area are a peculiar lime-green color from the clay mineral celadonite (Hay, 1963). This illitelike clay includes magnesium and more ferric than ferrous iron, and is thought to have formed by burial illitization of smectite in paleosols, lake beds, and basalts (Porrenga, 1968; Norrish and Pickering, 1983; Weaver, 1989). These paleosols are moderately developed (Inceptisols and Aridisols), thin (50 cm or less), clayey to silty profiles. They have abundant fine root traces and scattered large root traces near the surface (A horizon) over a white, nodular or massive, calcareous horizon (Bk). Their paleoclimate was presumably subhumid to semiarid, allowing accumulation of carbonate. The abundant fine root traces and lack of clayey subsurface (Bt) horizons are compatible with wooded grassland or open woodland vegetation, rather more open than would be expected from adaptive features of the mammalian fauna. The preservation of bones along with land snails and calcareous hackberry pits was favored by the calcareous composition of the paleosols, but the soils were too oxidized for the preservation of organic remains of plants (Retallack, 1983, 1984). The paleosols contain significant amounts of ferric iron, but have not been as thoroughly oxidized to red and brown colors as paleosols in the lower John Day Formation. These distinctive green paleosols may have been seasonally dry marsh soils, like alkaline flats around Lake Rukwa, Tanzania (Vesey-Fitzgerald, 1963). Parent material for the paleosols of the John Day Formation was mainly white air-fall ash derived from the ancestral Cascades with some admixture of clay and rock fragments from surrounding older sediments. The time for formation of these soils was on the order of thousands of years, because some of them have well-developed calcic horizons (Stage III in the developmental scheme of Gile and others, 1966).

**En route**

Return to the vehicles and continue south on Highway 19. It passes a spectacular exposure of John Day Formation, called "Cathedral Rock." This consists of the Turtle Cove Member and a thick ash-flow tuff of the John Day Formation, slumped down to create the large meander in the John Day River.

About 2 mi south of the bridge over the John Day River at Humphrey Ranch there is a roadside outcrop of sandstone and conglomerate on which the Tertiary sequence rests unconformably. These conglomerates are even better exposed in a bend of the John Day River to the south. The conglomerate is Early Cretaceous (Aptian to early Albian) in age (Aguirre and Fisk, 1987) and may have been deposited in braided streams or fan deltas (Kleinhans and others, 1984). Fossil plant fragments have been recovered from shale partings in the conglomerates and include cycadophytes (*Taeniopteris*) and conifers (*Elatocladus*: identifications by author from Condon collection, University of Oregon).

Farther south on Highway 19 is a sign indicating the Visitor Center of John Day Fossil Beds National Monument and then the junction with U.S. Highway 26. By this time it will be quite late in the day, and it is best to return to these outcrops on the next day, after staying overnight at John Day, 38 mi to the east along U.S. Highway 26.

**CONTINUED NEXT MONTH: PART 2 WITH ITINERARY FOR SECOND DAY**

# Oil and gas exploration and development in Oregon, 1990

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

**ABSTRACT**

Oil and gas lease activity in Oregon declined slightly in 1990. Four Bureau of Land Management (BLM) lease sales were held, with one lease purchased. Applications were filed for 67,881 federal acres. The total of federal acres under lease was 471,379 acres at year's end. No state or county lease sales were held during the year.

Five wells were drilled in the Mist Gas Field, of which three were exploratory wells drilled by Nehama and Weagant Energy Company, and two were service wells at the Mist Natural Gas Storage Project drilled by Northwest Natural Gas Company. One Nehama and Weagant Energy Company well was completed as a gas producer, one was an apparent gas producer but had not been flow-tested by year's end, and one was abandoned. The field had 19 gas producers and four completed wells awaiting pipeline connection at year's end. A total of 2.8 billion cubic feet (Bcf) of gas was produced during 1990, with a value of $3.9 million. ARCO abandoned 11 depleted wells during 1990.

Northwest Natural Gas Company injected and withdrew about 6 Bcf of gas at the Mist Natural Gas Storage Project. The gas is delivered to the Portland metropolitan area via the recently completed South Mist Feeder Pipeline.

The Department of Geology and Mineral Industries (DOGAMI) revised its rules for oil and gas drilling in Oregon and adopted new rules relating to drilling and reclamation requirements for shallow holes drilled in oil and gas exploration activities, such as seismic shot holes.

DOGAMI continues a study of the Tyee Basin, located in Douglas and Coos Counties, and has published reports and maps on the geology and oil, gas, and coal resources of the area.

During the legislative session, DOGAMI introduced two bills that affect the oil and gas industry. One will provide for civil penalty authority and the other will increase permit fees.

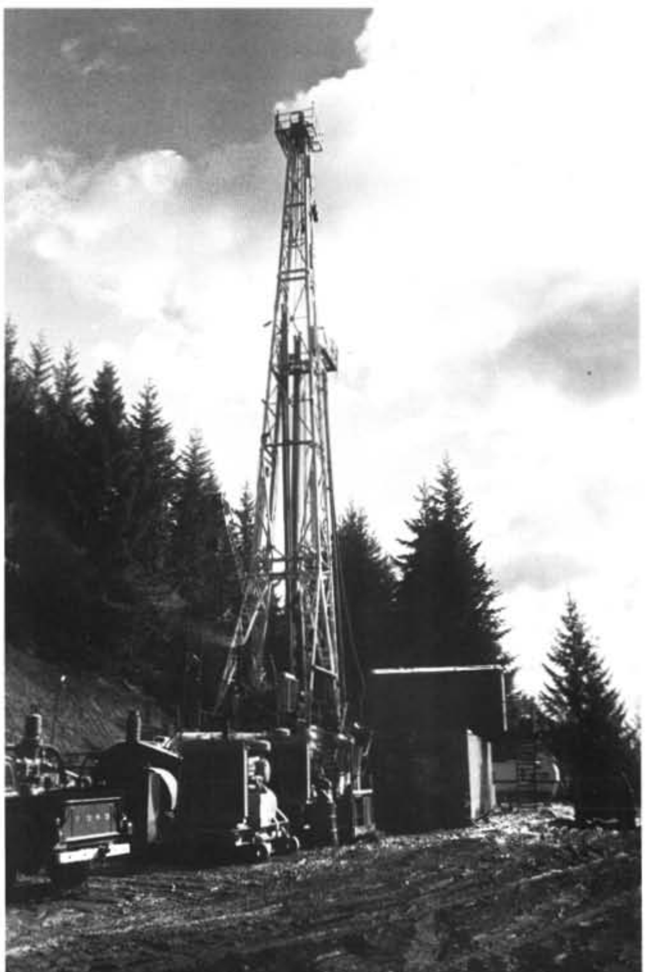


*Figure 1. Nehama and Weagant Energy Company drilled the well CER 11-16-64 and completed it as a successful gas producer at the Mist Gas Field. Drilling was performed by Rig 5 of Taylor Drilling Company.*

**LEASING ACTIVITY**

Leasing activity experienced a small decline during 1990, which is a continuation of the pattern in leasing that began during 1988. Activity included four public land sales by BLM as well as over-the-counter filings of BLM property. One lease was acquired during the BLM lease sale held in June 1990, when Oregon Natural Gas Development acquired a parcel in Washington County. This was the first bid on any parcel offered in Oregon at a BLM lease sale since the competitive bidding system was imposed. Applications were filed for 16 parcels totaling 67,881 acres located in Wheeler, Jefferson, and Washington Counties. These were filed by Norwestco, Inc., of Bend, Oregon, and by D.M. Yates of Portland, Oregon. Leases were issued on 23 parcels containing 80,018 acres located in Wheeler, Jefferson, Columbia, and Crook Counties. A total of 24 parcels comprising 72,167 acres was relinquished during the year, so that, at year's end, a total of 182 parcels comprising 471,379 acres were under lease. The total rental income during 1990 was about $520,000.

During the year, no State of Oregon leases were acquired. A total of 19 State of Oregon leases were relinquished consisting of 24,451 acres. At the end of 1990, active State of Oregon leases numbered 39, totaling 48,977 acres. Total rental income was $48,977 for the year.

No state or county lease sales were held during the year.

**DRILLING**

Three exploratory oil and gas wells and two injection-withdrawal service wells were drilled during 1990. This is a decline from the 14 exploratory oil and gas wells drilled during 1989. All of the wells were drilled at the Mist Gas Field, where most of the oil and gas drilling activity in Oregon has occurred since the field was discovered in 1979.

Of the two operators active during the year, Nehama and Weagant Energy Company was the most active, drilling the three exploratory oil and gas wells at Mist Gas Field. These wells were (1) CER 11-16-64, located in sec. 16, T. 6 N., R. 4 W., drilled to a total depth of 2,328 ft, and completed as a gas producer (Figure 1); (2) CER 41-21-64, located in sec. 21, T. 6 N., R. 4 W., drilled to a total depth of 2,121 ft, and suspended after the setting of production casing; and (3) LF 13-35-65, located in sec. 35, T. 6 N., R. 5 W., drilled to a total depth of 2,150 ft, and plugged and abandoned.

The two injection-withdrawal service wells drilled at the Mist Natural Gas Storage Project were drilled by Northwest Natural Gas Company which operates the project. The IW 32c-10, located in sec. 10, T. 6 N., R. 5 W., was drilled in the Flora Pool to

Table 1. *Oil and gas permits and drilling activity in Oregon, 1990*

| Permit no. | Operator, well, API number | Location | Status, depth(ft) TD=total depth PTD=proposed TD |
|---|---|---|---|
| 440 | Norwestco<br>1-29 Donnelly Dome<br>36-069-00009 | SW¼ sec. 29<br>T. 9 S., R. 23 E.<br>Wheeler County | Application;<br>PTD: 5,000. |
| 441 | NW Natural Gas<br>IW 13b-11<br>36-009-00267 | SW¼ sec. 11<br>T. 6 N., R. 5 W.<br>Columbia County | Permit issued;<br>PTD: 2,600 |
| 442 | NW Natural Gas<br>IW 33ac-3<br>36-009-00268 | SE¼ sec. 3<br>T. 6 N., R. 5 W.<br>Columbia County | Completed,<br>service well;<br>TD: 2,897. |
| 443 | NW Natural Gas<br>IW 23d-3<br>36-009-00269 | SW¼ sec. 3<br>T. 6 N., R. 5 W.<br>Columbia County | Permit issued;<br>PTD: 3,000. |
| 444 | NW Natural Gas<br>IW 32c-10<br>36-009-00270 | NE¼ sec. 10<br>T. 6 N., R. 5 W.<br>Columbia County | Completed,<br>service well;<br>TD: 2,749. |
| 445 | Nehama & Weagant<br>CER 12-12-55<br>36-009-00271 | NW¼ sec. 12<br>T. 5 N., R. 5 W.<br>Columbia County | Application;<br>PTD: 2,000. |
| 446 | Nehama & Weagant<br>LF 13-35-65<br>36-009-00272 | SW¼ sec. 35<br>T. 6 N., R. 5 W.<br>Columbia County | Abandoned,<br>dry hole;<br>TD: 2,150. |
| 447 | Nehama & Weagant<br>CER 41-21-64<br>36-009-00273 | NE¼ sec. 21<br>T. 6 N., R. 5 W.<br>Columbia County | Suspended;<br>TD: 2,121. |
| 448 | Nehama & Weagant<br>CER 22-16-64<br>36-009-00274 | NW¼ sec. 22<br>T. 6 N., R. 4 W.<br>Columbia County | Application;<br>PTD: 2,500. |
| 449 | Nehama & Weagant<br>CER 11-16-64<br>36-009-00275 | NW¼ sec. 16<br>T. 6 N., R. 4 W.<br>Columbia County | Completed, gas;<br>TD: 2,328. |
| 451 | Nehama & Weagant<br>CER 14-16-64<br>36-009-00277 | SW¼ sec. 16<br>T. 6 N., R. 4 W.<br>Columbia County | Application;<br>PTD: 2,500. |

a total depth of 2,897 ft; and the IW 33ac-3, located in sec. 10, T. 6 N., R. 5 W., was drilled in the Bruer Pool to a total depth of 2,749 ft.

Total drilling footage for the year was 12,245 ft, a decrease from the 33,823 ft drilled during 1989. The average depth per well was 2,449 ft, a small increase from the 2,416 ft per well drilled during 1989.

During 1990, DOGAMI issued 8 permits to drill (Table 1) while 5 permits were canceled during the year (Table 2).

ARCO Oil and Gas Company performed, at Mist Gas Field, a multi-well program in which 11 wells were plugged and abandoned and three wells were reperforated for return to production. The plugged and abandoned wells were depleted producers no longer capable of commercial production. These include the CFI 12-1-55 (Figure 2), CC#4 RD#1, CC 43-27-65, LF 12-33-75, Busch 14-15-65, Foster 42-30-65, LF 11-31-64, CC 34-4-65, LF 23-36-65, LF 41-35-65, and CC 11-34-65. The reperforated wells were the CFI 34-1-55, CC 21-35-65, and LF 23-25-65.

DY Oil Company reperforated the Neverstill 33-30 well and returned it to production during the year (Figure 3).

## DISCOVERIES AND GAS PRODUCTION

Mist Gas Field saw one new producer, and one suspended well that is an apparent producer but had not yet been flow-tested by year's end. This is a decrease from the four new producers in

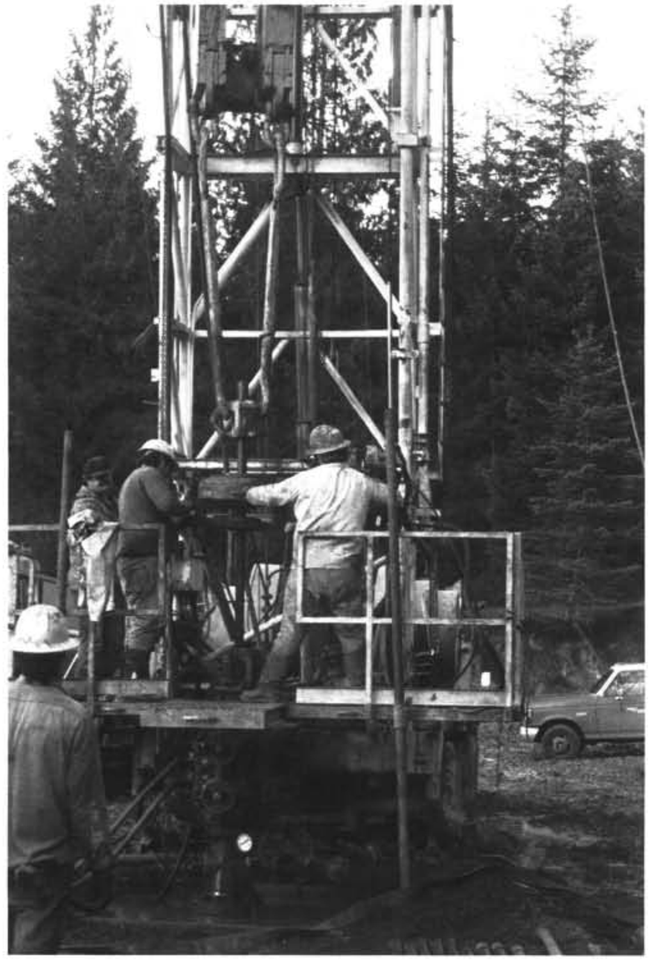


*Figure 2. ARCO well CFI 12-1-55 was plugged along with 10 other depleted producers at Mist Gas Field.*

1989. Nehama and Weagant Energy Company is the operator of the new producer, the CER 11-16-64, and the suspended indicated producer, the CER 41-21-64.

At the end of 1990, three companies were operating 19 gas producers at Mist Gas Field: ARCO Oil and Gas Company, DY Oil Company, and Nehama and Weagant Energy Company. In addition, four wells were suspended, awaiting pipeline connection.

Gas production for the year totaled 2.8 Bcf. This is an increase from the 2.5 Bcf of gas produced during 1989. The cumulative field production as of the end of 1990 was about 41.2 Bcf of gas. The total value of the gas produced for the year was $3.9 million, an increase from the $3.5 million during 1989. Gas prices ranged from 14 cents to 15 cents per therm, which is about the same as during 1989.

## GAS STORAGE

During the year, Northwest Natural Gas Company drilled two new service wells at the Mist Natural Gas Storage Project. The IW 32c-10 is an injection-withdrawal well drilled in the Flora Pool, and the IW 33ac-3 is an injection-withdrawal well drilled in the Bruer Pool. The storage project now has a total of seven injection-withdrawal wells; three in the Flora Pool and four in the Bruer Pool. These pools have a combined storage capacity of 10 Bcf of gas. This allows for cycling the reservoirs between approximately 400 psi to 1,000 psi and will provide for an annual delivery of one million therms per day for about 100 days. During the year, about 6.0 Bcf of gas was injected and withdrawn from the gas storage projects. This gas is delivered to the Portland metropolitan area via the recently competed South Mist Feeder Pipeline.

## OTHER ACTIVITIES

The administrative rules relating to oil and gas exploration and development in Oregon were revised during 1990. This revision was done as a triannual rule review, and led to several changes. In addition, new administrative rules relating to shallow oil and gas exploration holes drilled in Oregon were adopted during the year. These new rules were developed to provide for ground-water protection and reclamation whenever shallow holes are drilled in oil and gas exploration activities, such as seismic shot holes and stratigraphic core holes. Copies of these rules (OAR 632, Division 15) are available free from DOGAMI.

DOGAMI continues the study of the oil and gas potential of the Tyee Basin, located primarily in Douglas and Coos Counties in southwestern Oregon. The study, which is funded by landowners in the study area and by county, state, and federal agencies, is intended to investigate those characteristics needed to generate and trap gas and oil: source rock, stratigraphy, and structural framework. The first phase of the study resulted in the publication of DOGAMI Open-File Report O-89-3, *Geology and Oil, Gas, and Coal Resources, Southern Tyee Basin, Southern Coast Range, Oregon*. This report includes the stratigraphic and structural framework and source rock data of the Tyee Basin and is available from DOGAMI ($10). During 1990, a detailed geologic map of the Reston 7½-minute Quadrangle was published and is available from DOGAMI as map GMS-68 ($6). This geologic map has led to a revision of the understanding of the geologic framework of the Tyee Basin. During 1991, a fence diagram will be published that will tie surface and subsurface data and geophysical data together. In addition, a detailed geologic map of the Camas 7½-minute Quadrangle will be published during the year.

Table 2. *Canceled permits, 1990*

| Permit no. | Operator, well, API number | Location | Issue date | Cancellation date | Reason |
|---|---|---|---|---|---|
| 421 | ARCO<br>Col. Co. 42-32-74<br>36-009-00250 | NE¼ sec. 32<br>T. 7 N., R. 4 W.<br>Columbia Co. | 4-17-89 | 4-17-90 | Permit canceled; expired. |
| 426 | LEADCO<br>CC-Jackson 23-17<br>36-009-00255 | SW¼ sec. 17<br>T. 5 N., R. 4 W.<br>Columbia Co. | 7-19-89 | 7-19-90 | Permit canceled; expired. |
| 434 | ARCO<br>Col. Co. 13-3-55<br>36-009-00263 | SW¼ sec. 3<br>T. 5 N., R. 5 W.<br>Columbia County | 8-28-89 | 8-29-90 | Permit canceled; expired. |
| 435 | ARCO<br>Col. Co. 13-4-54<br>36-009-00264 | SW¼ sec. 4<br>T. 5 N., R. 4 W.<br>Columbia County | 8-28-89 | 8-29-90 | Permit canceled; expired. |
| 450 | Nehama & Weagant<br>CC 23-35-75<br>36-009-00276 | SW¼ sec. 35<br>T. 7 N., R 5 W.<br>Columbia County | 9-17-90 | 11-29-90 | Permit canceled; by permittee's request. |

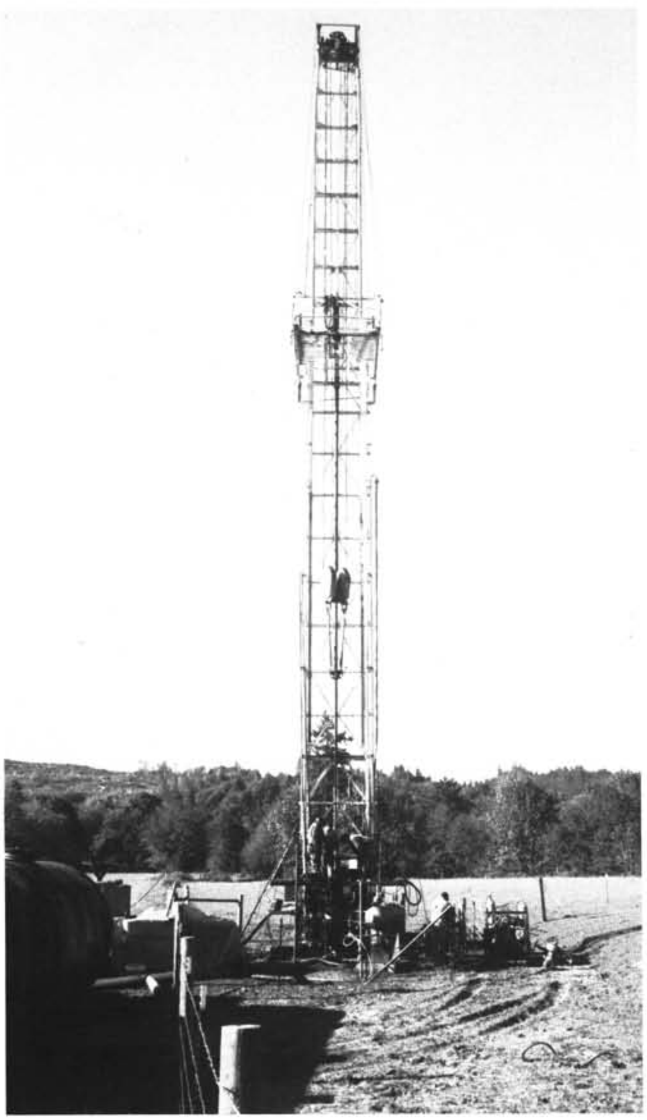


*Figure 3. DY Oil Company reperforated the well Neverstill 33-30 during 1990 and returned it to production.*

During 1990, a transect was published by DOGAMI which presents a geological and geophysical cross section extending from the Mist Gas Field to the northwest Oregon continental shelf and slope. This publication, OGI-17, is available from DOGAMI ($10).

The Northwest Petroleum Association remained active during 1990 and had about 130 members at year's end. At monthly meetings, papers related to the oil and gas industry are presented. For 1991, plans are to hold the annual symposium in the Bellingham Basin in the northern Puget Sound, Washington.

During the year, the U.S. Minerals Management Service placed a moratorium on a planned oil and gas lease sale for the outer continental shelf off Oregon and Washington for a 10-year period through the year 2000. The sale was originally scheduled for 1992. During the 10-year moratorium on leasing, a study of the environmental effects of oil and gas activity is to be conducted.

Columbia County will hold a lease auction during 1991. Some 120 parcels comprising about 46,000 acres will be offered for oral bid. Details can be obtained from the Columbia County Commissioners Office, St. Helens, Oregon.

DOGAMI has introduced two bills during the current legislative session which may affect the oil and gas industry. One bill will give the agency civil penalty authority as part of its oil and gas regulatory program. Another bill will increase permit fees for oil and gas drilling in Oregon. Copies of these bills are available free from DOGAMI. □

# Mining and exploration in Oregon during 1990

*by Thomas J. Wiley, Regional Geologist, Grants Pass Field Office, Oregon Department of Geology and Mineral Industries*

**ABSTRACT**

Mineral production of about $225 million is anticipated in 1990, primarily from sand, gravel, cement, crushed stone, and nickel operations. Glenbrook Nickel produced 8.3 million pounds of nickel, a ten-fold increase in production over 1989. Formosa Resources Silver Peak Mine in Douglas County is producing copper, zinc, silver, and gold. Atlas Precious Metals Company continues permitting, environmental monitoring, and definition drilling for its Grassy Mountain gold prospect in Malheur County. Exploration in the Lake Owyhee region has reached the prospect evaluation phase, while broad reconnaissance has shifted northward to early Tertiary intrusions and vein systems in pre-Tertiary rocks. The Oregon Department of Geology and Mineral Industries (DOGAMI) is beginning a new geologic mapping and sampling program in southern Oregon to assess mineral resources of the Western Cascades.

## NEW DEVELOPMENTS IN OREGON DURING 1990

The U.S. Bureau of Mines (USBM) estimate of mineral production value for 1990 is $225 million, primarily from sand, gravel, cement, crushed stone, and nickel operations (Table 1). The USBM estimate of 1989 production included $55 million worth of metals and industrial minerals; this figure rose to $89 million during 1990, largely as a result of increased production at Glenbrook Nickel. The Oregon Department of Geology and Mineral Industries (DOGAMI) values natural gas produced from Columbia County's Mist Gas Field at about 4 million dollars for 1990. Active mines and exploration sites are shown on Figure 1.

Table 1. *Summary of mineral production value (in millions of dollars) in Oregon for the last 19 years. Data for 1990 derived from U.S. Bureau of Mines annual preliminary mineral-industry survey and Oregon Department of Geology and Mineral Industries natural-gas statistics.*

| | Rock materials[1] | Metals and industrial minerals[2] | Natural gas | Total |
|---|---|---|---|---|
| **1972** | 54 | 22 | 0 | 76 |
| **1973** | 55 | 26 | 0 | 81 |
| **1974** | 75 | 29 | 0 | 104 |
| **1975** | 73 | 33 | 0 | 106 |
| **1976** | 77 | 35 | 0 | 112 |
| **1977** | 74 | 35 | 0 | 109 |
| **1978** | 84 | 44 | 0 | 128 |
| **1979** | 111 | 54 | + | 165 |
| **1980** | 95 | 65 | 12 | 172 |
| **1981** | 85 | 65 | 13 | 163 |
| **1982** | 73 | 37 | 10 | 120 |
| **1983** | 82 | 41 | 10 | 133 |
| **1984** | 75 | 46 | 8 | 129 |
| **1985** | 91 | 39 | 10 | 140 |
| **1986** | 96 | 30 | 9 | 135 |
| **1987** | 102 | 52 | 6 | 160 |
| **1988** | 130 | 48 | 6 | 184 |
| **1989** | 131 | 55 | 4 | 190 |
| **1990** | 132 | 89 | 4 | 225 |

[1] Includes sand, gravel, and stone.

[2] For 1990, this includes cement; clays, including bentonite; copper-zinc; diatomite; gemstones, including Oregon sunstone; gold-silver; nickel; perlite; pumice; quartz; silica sand; talc, including soapstone; and zeolites.

The construction minerals segment of the industry will be affected by changing growth patterns in the state. Preliminary 1990 population figures released by the U.S. Census Bureau show a state-wide increase of about 200,000 residents since 1980; this brings the state's population to 2.8 million. Five counties experienced ten-year growth rates of 15 percent or more; four of these are in the Portland area. Deschutes County grew 20 percent. Three counties in north-central Oregon showed population declines greater than 10 percent. Overall, the population increased in 23 of 36 counties.

## PRODUCTION HIGHLIGHTS

### Eastern Oregon

The Bonnanza placer mine (Mine site 2, Table 2) on Pine Creek in Baker County remains the state's largest gold producer. Work is limited to April through November. At full production, the mine runs two shifts and employs 25 to 30 people. Reclamation and habitat improvement on mined areas has been concurrent with production; the northern part of the site has already been reclaimed. Mining at the current rate, the deposit will be mined out during the year 1991.

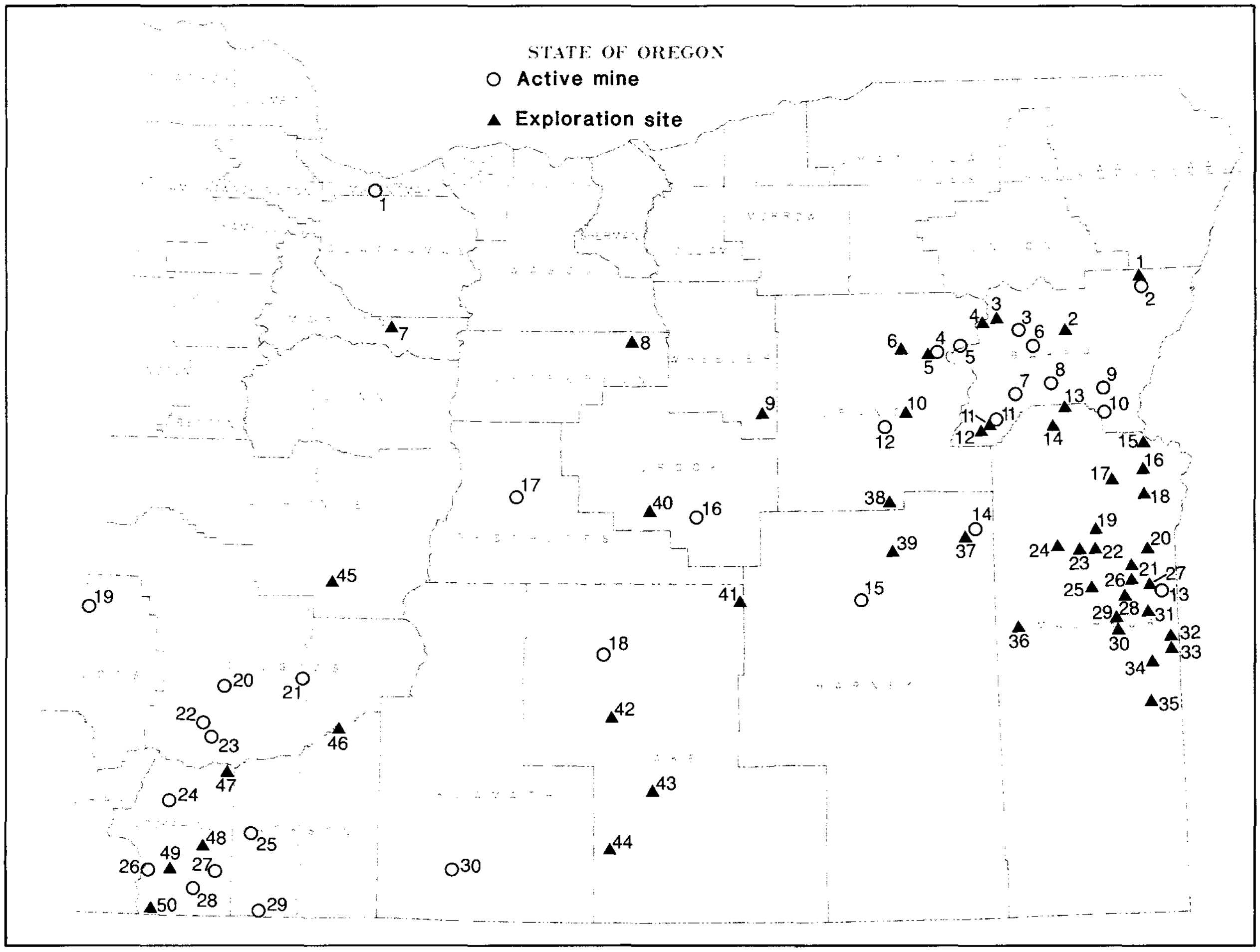
Ash Grove Cement West, Inc., near Baker (Mine site 9, Table 2) achieved capacity production of 500,000 tons of cement and 220,000 tons of crushed limestone (sold as "sugar rock") during 1990. This represents a small increase in production over 1989. The company employs 105 workers.

The Ponderosa Mine (Mine site 15, Table 2) in Harney County near Hines is processing altered basalt to produce sunstone, a variety of feldspar that is Oregon's state gem. One Track Mines and Western Consolidated cooperated to produce 200 kg (440 lbs) of sunstone valued at $250,000 in 1990. This represents a 100-percent increase over 1989 levels, and production is expected to double again in 1991. Average grade is about 0.1 kg per ton (0.22 lbs/ton). Some stones are valued at more than $1,000 per carat.

### Western Oregon

Glenbrook Nickel (Mine site 22, Table 2; Figure 2) estimates that 1990 production has increased an order of magnitude above 1989 levels. In 1989, 150,000 dry tons of stockpiled ore reached the furnaces, and 750,000 lbs of nickel was produced as ferronickel. In 1990, Glenbrook estimates, 600,000 tons of ore reached the smelter, and 8.35 million pounds of nickel was produced with a value near $33 million (based on a nickel price of $4/lb). Glenbrook has begun mining fine-grained ore from waste dumps and abandoned settling ponds to improve the size mix of furnace feed. The company is developing a plan to mine high-grade pods of ore from Nickel Mountain.

Formosa Resource's Silver Peak Mine (Mine site 23, Table 2; Figure 3) has begun producing copper, zinc, silver, gold, and possibly sulfur from a Kuroko-type massive-sulfide deposit near Riddle in Douglas County. Formosa geologist Will Beach reports a resource of about 425,000 tons grading two percent zinc, three percent copper, 0.045 oz/ton gold, and 1 oz/ton silver. The deposit is characterized by a combination of early soft-sediment deformation of massive sulfide lenses and subsequent structural dismemberment, the latter possibly related to the Coast Range fault that crops out a few hundred meters to the west. The company is installing a 200 ton per day mill and plans to increase output to 400 tons per day. Concentrates will be hauled to Vancouver, Washington, and then shipped to Japan for smelting. Waste rock will be backfilled in the underground workings.




## EXPLANATION

### Active Mines and Areas

1. Columbia Brick Works
2. Bonanza Mine (placer gold)
3. Deer Creek (placer gold)
4. Big Creek (placer gold)
5. Greenhorn area (placer gold)
6. Elk Creek (placer gold)
7. Pine Creek (placer gold)
8. Dooley Mountain (perlite)
9. Ash Grove Cement West (cement and crushed limestone)
10. Rye Valley/Mormon Basin (placer gold)
11. Lower Grandview Mine (placer gold)
12. Canyon City Placers (placer gold)
13. Teague Mineral Products (bentonite and clinoptilolite)
14. Eagle-Picher Industries (diatomite)
15. Ponderosa Mine (Oregon sunstone)
16. Central Oregon Bentonite/Oregon Sun Ranch (bentonite clay)
17. Cascade Pumice/Central Oregon Pumice
18. Oil-Dri Production (diatomite)
19. CooSand (silica sand)
20. Oregon Portland Cement (limestone)
21. Quartz Mountain (silica)
22. Nickel Mountain (nickel)
23. Silver Peak (copper, zinc, gold, silver)
24. Galice area (placer gold)
25. Bristol Silica and Limestone (silica)
26. Josephine Creek area (placer gold)
27. Jones Marble quarry (agricult. limestone)
28. Sucker Creek area (placer gold)
29. Steatite of Southern Oregon (soapstone)
30. Klamath Falls Brick and Tile

### Exploration Sites and Areas

1. Cornucopia Mine (lode gold)
2. White Swan—U.P. (lode gold)
3. Bourne (gold, silver)
4. Herculean Mine (gold and base metals)
5. Mammoth (gold, silver, copper)
6. Susanville (lode gold)
7. Bornite (copper, gold, silver)
8. Red Jacket (lode gold)
9. Spanish Gulch (lode gold)
10. Prairie Diggings (lode gold)
11. Record and Grouse Creek (gold, copper)
12. Grouse Creek (copper, silver)
13. Racey property (lode gold)
14. Cow Valley Butte (lode gold)
15. Kerby/East Ridge (lode gold)
16. Tub Mountain area (lode gold)
17. Hope Butte (lode gold)
18. Vale Butte (lode gold)
19. H claims (lode gold)
20. Calavera (lode gold)
21. Grassy Mountain (lode gold)
22. Harper Basin (lode gold)
23. BCMX (lode gold)
24. Gold Creek area (lode gold)
25. Freeze (lode gold)
26. Burnt Mountain area (lode gold)
27. Camp Kettle (lode gold)
28. Dry Creek Buttes area (lode gold)
29. Jessie Page (lode gold)
30. Red Butte (lode gold)
31. South Owyhee Ridge area (lode gold)
32. Bannock (lode gold)
33. Mahogany (lode gold)
34. Mahogany Gap and Storm (lode gold)
35. Jordan Valley area (lode gold)
36. Stockade area (lode gold)
37. Drewsey area (lode gold)
38. Baboon Creek (limestone)
39. Idol City area (lode gold)
40. Bear Creek Butte (lode gold)
41. Glass Butte (lode gold)
42. Summer Lake area (lode gold)
43. Paisley area (lode gold)
44. Quartz Mountain (lode gold)
45. Bohemia District (lode gold)
46. Prospect Silica (silica)
47. Martha Mine (lode gold)
48. Marble Mountain (limestone)
49. Eight Dollar Mountain (nickel laterite)
50. Turner-Albright (copper, zinc, gold)

*Figure 1. Mining and mineral exploration sites in Oregon in 1990, excluding sand, gravel, and stone. Active mines are keyed to Table 2; exploration sites are keyed to Table 3.*

Table 2. *Active mines in Oregon, 1990*

| No. | Mine name | Company | Commodity | Location | Remarks |
|---|---|---|---|---|---|
| 1 | — | Columbia Brick Works | Brick | Sec. 14, T. 1 S., R. 3 E., Multnomah County | — |
| 2 | Bonnanza | Bonnanza Mining Company | Placer gold | Sec. 3, T. 7 S., R. 45 E., Baker County | Oregon's largest producing gold mine; reclamation and mining are concurrent. Company plans to close mine during 1991. |
| 3 | Deer Creek | Cammtex International, Inc. | Placer gold | Sec. 30, T. 9 S., R. 38 E., Baker County | Reopened after a two-year lapse in operation. |
| 4 | Big Creek | — | Placer gold | T. 10 S., R. 34 E., Grant County | — |
| 5 | Greenhorn area | — | Placer gold | Tps. 9, 10 S., R. 35 E., Baker and Grant Counties | — |
| 6 | Elk Creek | — | Placer gold | Tps. 9, 10 S., R. 39 E., Baker County | — |
| 7 | Pine Creek | — | Placer gold | T. 12 S., R. 38 E., Baker County | — |
| 8 | Dooley Mountain | Supreme Perlite Company | Perlite | Tps. 11, 12 S., R. 40 E., Baker County | Produced 1,000 tons during 1990. |
| 9 | — | Ash Grove Cement West, Inc. | Cement, crushed limestone | Sec. 11, T. 12 S., R. 43 E., Baker County | Reached capacity production of 500,000 tons of cement plus 200,000 tons of limestone; employs 105. |
| 10 | Rye Valley/ Mormon Basin area | — | Placer gold | T. 13 S., Rs. 42, 43 E., Baker County | — |
| 11 | Lower Grandview | — | Lode gold | Sec. 6, T. 14 S., R. 37 E., Baker County | Mill tailings hauled to cyanide-leach facility in Nevada. New drift of 400 ft. Mine closed. |
| 12 | Canyon City Placers | Cammtex International, Inc. | Placer gold | Sec. 6, T. 14 S., R. 32 E., Grant County | Reclaimed and closed during 1990. |
| 13 | — | Teague Mineral Products | Bentonite and clinoptilolite | Secs. 28, 29, T. 23 S., R. 46 E., Malheur County (and nearby Idaho) | Plant located Sec. 8, T. 23 S., R. 46 E. Company reports increasing sales, including Europe and Latin America. |
| 14 | Eagle-Picher | Eagle-Picher Industries, Inc. | Diatomite | Tps. 19, 20 S., R. 35, 36 E., Malheur and Harney Counties | Plant located Sec. 6, T. 19 S., R. 44 E. |
| 15 | Ponderosa Mine | One Track Mines/ W. Consolidated | Oregon sunstone | T. 23 S., R. 30 E., Harney County | Produced 200 kg gemstones in 1990. Company plans to double production in 1991. |
| 16 | — | Central Oregon Bentonite Co./ Oregon Sun Ranch, Inc. | Bentonite | Sec. 4, T. 19 S., R. 21 E., Crook County | Produced about 10,000 tons in 1990 for cat litter, road construction material, and pond linings. |
| 17 | — | Cascade Pumice Co./Central Oregon Pumice Company | Pumice | Tps. 17, 18 S., R. 11 E., Deschutes County | — |
| 18 | — | Oil-Dri Production Company | Diatomite | Secs. 14, 21, 23, T. 26 S., R. 16 E., Lake County | — |
| 19 | — | CooSand Corporation | Silica sand | Sec. 34, T. 24 S., R. 13 W., Coos County | Product used for glass, foundry work, and traction. Company patented several sand claims near Oregon Dunes; employs five in Oregon. |
| 20 | Oregon Portland Cement quarry | Mountain Valley Resources | Limestone | Sec. 20, T. 28 S., R. 5 W., Douglas County | Formerly D and D Ag Lime and Rock Company. |
| 21 | Quartz Mountain | — | Silica | Sec. 2, T. 28 S., R. 1 W., Douglas County | — |
| 22 | Nickel Mountain | Glenbrook Nickel Company | Nickel | Secs. 28, 29, T. 30 S., R. 6 W., Douglas County | Tenfold increase in production; very limited mining. |
| 23 | Silver Peak Mine | Formosa Resources, Inc. | Copper, zinc, gold, silver | Sec. 23, T. 31 S., R. 6 W., Douglas County | Began producing at end of 1990. |
| 24 | Galice area | — | Placer gold | Tps. 34, 35 S., R. 8 W., Josephine County | — |
| 25 | — | Bristol Silica and Limestone Company | Silica | Sec. 30, T. 36 S., R. 3 W., Jackson County | — |
| 26 | Josephine Creek area | — | Placer gold | Tps. 38, 39 S., R. 9 W., Josephine County | — |
| 27 | Jones Marble quarry | Campman Calcite Company | Agricultural limestone | Sec 31, T. 38 S., R. 5 W., Josephine County | Closed. |
| 28 | Sucker Creek area | — | Placer gold | Tps 39, 40 S., Rs. 6, 7 W., Josephine County | — |
| 29 | — | Steatite of Southern Oregon | Soapstone | Secs. 10, 11, T. 41 S., R. 3 W., Jackson County | Acquired adjacent land. |
| 30 | — | Klamath Falls Brick and Tile Co. | Brick | Sec. 19, T. 38 S., R. 9 E., Klamath County | New markets in Washington and California; employs 26. |

*Figure 2. Glenbrook Nickel plant near Riddle (Mine site 22, Table 2) increased its production 1,000 percent from 1989 to 1990. Eight million pounds of nickel (as ferronickel) was produced from 600,000 tons of ore smelted during 1990.*

*Figure 3. Formosa Resources' Silver Peak Mine (Mine site 23, Table 2) is producing copper, zinc, silver, and gold. Mill and settling pond are located on the ridge crest, and ore is trucked to the mill from the portal at left.*

Inspiration Resources Corporation purchased LTM, Inc., and Rogue Aggregate, Inc., the largest producers of sand, gravel, and crushed rock in Jackson County. A DOGAMI review of Jackson County aggregate was stimulated by a 1970 estimate that the resource would be exhausted sometime between 1985 and 2005. Additional resources have been discovered since 1970, and there is currently a reserve base that should last well into the 21st century.

Campman Calcite has rebuilt the road to the Marble Mountain limestone quarry (Exploration site 48, Table 3) outside Grants Pass and terminated operations in the Jones Marble quarry (Mine site 27, Table 2) near Williams.

**Placer gold**

In addition to the Bonnanza placer described above, several small placer mines opened and operated intermittently on Sucker Creek (Mine site 28, Table 2), Josephine Creek (Mine site 26, Table 2), and in the Galice area (Mine site 24, Table 2) in Josephine County; on Deer Creek (Mine site 3, Table 2), Elk Creek (Mine site 6, Table 2), and in Rye Valley (Mine site 10, Table 2) in Baker County; in the Mormon Basin (Mine site 10, Table 2) near the Baker County-Malheur County line; and on Big Creek (Mine site 4, Table 2) in Grant County.

## EXPLORATION HIGHLIGHTS

### Eastern Oregon

Malheur Mining's Kerby/East Ridge prospect (Exploration site 15, Table 3) saw an additional 90 drill holes completed, including 6 core holes, to bring the total to 340 holes. Airborne EM resistivity studies, bulk sampling, and pilot metallurgical studies were undertaken during 1990. Environmental monitoring is in its second year.

Developments in the private sector have involved a large number of negotiations to create partnerships and joint ventures. Horizon Gold Shares, Inc., entered a joint venture with Chevron Resources Company at Hope Butte (Exploration site 17, Table 3) in northern Malheur County. This year, Horizon added 26 drill holes to the 77 holes drilled by Chevron. More than 30 holes have already been reclaimed. Cultural and small-mammal surveys are complete, an air-quality monitor is going up, and a ground-water monitoring well has been drilled.

Atlas Precious Metals Company has begun the permit process for the 1.2-million-ounce Grassy Mountain gold prospect (Exploration site 21, Table 3) in Malheur County. The U.S. Bureau of Land Management reports that the Final Scoping Document and Final Study Plan are completed and the draft environmental impact statement should be finished by next summer. A feasibility study indicates the potential for 100,000 troy oz of gold per year and a similar amount of silver for at least eight years. A six million dollar annual payroll supporting 190 jobs is projected.

Chevron Resources granted MK Gold of Boise a 40-percent interest in the Jessie Page (Quartz Mountain) property (Exploration site 29, Table 3) near Vale, Malheur County. Operating from its camp at the site, Chevron completed about 140 new drill holes this year.

Pegasus Gold Corporation is presently in the second year of a two-year option with Wavecrest Resources at the Quartz Mountain prospect (Exploration site 44, Table 3) in Lake County, where the current emphasis is on feasibility studies and problematic metallurgy of sulfide ores. An additional 28 development holes and 19 large-diameter core holes were drilled in 1990. Baseline environmental studies are ongoing.

Exploration in the Lake Owyhee "gold rush" region has generally shifted to the prospect evaluation phase, while broad reconnaissance exploration has moved elsewhere in eastern Oregon. New plays receiving attention in eastern Oregon include the following:

(1) Disseminated ore associated with vein systems in pre-Tertiary rocks, such as the Mammoth Property (Exploration site 5, Table 3) in Grant County, where Formation Capital Corporation has combined the Stalter, Pioneer, Golden West, and Wray Mine properties into a single prospect with gold-copper (Stalter) and gold-silver (Pioneer) targets. Gold and copper were produced from wide zones of quartz veins and stockworks in granodiorite and greenstone that typify this part of the Greenhorn District.

(2) Disseminated deposits associated with late Eocene to early Oligocene intrusives in argillite and flysch such as Manville's Record/Grouse Creek prospect (Exploration site 11, Table 3) in southwest Baker County.

Baker County is seeing some new underground activity, as J.R. Simplot Resources' Bourne project opens a new drift along the E and E portion of the North Pole-Columbia Lode (Exploration site 3, Table 3) in the Cracker Creek District near Sumpter. The Cracker Creek "vein" is a compound quartz-argillite breccia/vein system that cuts the Elkhorn Argillite. The company plans to drill during 1991.

Bond Gold Exploration Company's Red Jacket prospect (Exploration site 8, Table 3) extends the area of recent gold exploration activity into Jefferson County. Company geologists completed 12 drill holes during 1990 and conducted geophysical investigations and geologic mapping.

Table 3. *Exploration sites in Oregon, 1990*

| No. | Mine name | Company | Commodity | Location | Remarks |
|---|---|---|---|---|---|
| 1 | Cornucopia Mine | UNC Corporation | Lode gold | Sec. 27, T. 6 S., R. 45 E., Baker County | — |
| 2 | White Swan-U.P. | Gold River Exploration | Lode gold | T. 9 S., R. 41 E., Baker County | Trenching and underground mapping. |
| 3 | Bourne (N. Pole-Columbia Lode) | J.R. Simplot Resources | Gold, silver | T. 8 S., R. 37 E., Baker County | More than 20 core holes; retimbered workings. |
| 4 | Herculean Mine | Cable Cove Mining Company | Gold, base metals | Sec. 22, T. 8 S., R. 36 E., Baker County | Underground exploration. |
| 5 | Mammoth | Formation Capital Corporation | Gold, silver, copper | Secs. 8, 17, T. 10 S., R. 34 E., Grant County | 190 claims, combined Stalter, Pioneer, Golden West, and Wray mines; opened workings, trenching, soil sampling, geologic mapping. |
| 6 | Susanville | Cradle Mountain Resources, Am. Copper and Nickel jt. venture | Lode gold | Tps. 9, 10 S., Rs. 32, 33 E., Grant County | ACNC drilled 3 core holes before joint venture. |
| 7 | Bornite | Plexus Resources Corporation | Copper, gold, silver | Sec. 36, T. 8 S., R. 4 E., Marion County | Drilled 16 holes. Increased reserves beyond 2.8 million tons reported in 1989. |
| 8 | Red Jacket | Bond Gold Exploration, Inc. | Lode gold | T. 9 S., R. 17 E., Jefferson County | Drilled 12 holes; geologic mapping, geophysics. |
| 9 | Spanish Gulch | ASARCO, Inc. | Lode gold | T. 13 S., Rs. 24, 25 E., Wheeler County | Drilled 2 holes. |
| 10 | Prairie Diggings prospect | Western Gold Exploration and Mining Company | Lode gold | Sec. 33, T. 13 S., R. 32 E., Grant County | Drilled. |
| 11 | Record/ Grouse Creek prospects | Manville Corporation | Gold, copper | T. 14 S., Rs. 36, 37 E., Baker County | Drilled 12 holes; bulk sampling for geochemistry. |
| 12 | Grouse Creek prospect | Golconda Resources, Ltd. | Copper, silver | Secs. 24, 25, T. 14 S., R. 36 E., Baker County | — |
| 13 | Racey property | Billiton Minerals USA and ICAN Minerals, Ltd., joint venture | Lode gold | Tps. 12, 13 S., Rs. 40, 41 E., Malheur County | Billiton enlarged the project area through a joint venture with Earth Search Sciences, Inc., Goldsearch, and Beaver Resources on adjacent Shasta Butte properties, drilled 65 holes, and sampled in 28 trenches. |
| 14 | Cow Valley Butte | Cambiex USA, Inc. | Lode gold | T. 14 S., R. 40 E., Malheur County | Soil sampling and surface sampling along 2 mi of new road. |
| 15 | Kerby/ East Ridge | Malheur Mining Company | Lode gold | Secs. 22, 27, T. 15 S., R. 45 E., Baker County | Six core holes and 84 r-c holes drilled during 1990 for a total of 340 holes at the prospect; geophysics, pilot metallurgy, and continued environmental monitoring. |
| 16 | Tub Mountain area | Atlas Precious Metals, Inc., Euro-Nevada Mining Corporation, Echo Bay Exploration, Inc. | Lode gold | Tps. 16, 17 S., R. 45 E., Malheur County | Geologic mapping by Atlas, drilling and geophysics at Echo Bay's Hot Tub prospect. |
| 17 | Hope Butte | Horizon Gold Shares, Inc., and Chevron Resources Company | Lode gold | Sec. 21, T. 17 S., R. 43 E., Malheur County | Joint venture, 123 claims; drilled 26 holes, reclaimed drill holes; environmental monitoring continues, permitting underway. |
| 18 | Vale Butte | Atlas Precious Metals, Inc. | Lode gold | Secs. 28, 29, T. 18. S., R. 45 E., Malheur County | Geologic mapping and surface sampling. |
| 19 | H claims | U.S. Gold | Lode gold | Secs. 2, 10, 11, T. 20 S., R. 42 E., Malheur County | 44 claims, geologic mapping and sampling. |
| 20 | Calavera | Nerco Exploration Company | Lode gold | T. 21 S., R. 45 E., Malheur County | Drilling, surface sampling, and geologic mapping. |
| 21 | Grassy Mountain | Atlas Precious Metals, Inc. | Lode gold | Sec. 8, T. 22 S., R. 44 E., Malheur County | 981 claims; drilling, water wells. BLM released Final Scoping Document and Final Study Plan; Atlas completed a feasibility study. |
| 22 | Harper Basin | American Copper and Nickel Company, Inc., and Atlas Precious Metals, Inc. | Lode gold | T. 21 S., R. 42 E., Malheur County | 90 claims; Atlas drilled one hole. |
| 23 | BCMX | American Copper and Nickel Company, Inc. | Lode gold | Secs. 10, 11, 14, 15, T. 21 S., R. 41 E., Malheur County | Geologic mapping and geophysics. |
| 24 | Gold Creek area | Manville Corporation | Lode gold | Secs. 3, 4, 10, T. 21 S., R. 40 E., Malheur County | 33 claims; geologic mapping and geophysics. |
| 25 | Freeze | Western Mining Corporation and Larry Smith | Lode gold | T. 23 S., R. 42 E., Malheur County | 169 claims; 32 holes drilled; geophysics, geologic mapping, and geochemistry. |
| 26 | Burnt Mountain area | Noranda Exploration, Inc., Echo Bay Exploration, Inc. | Lode gold | Tps. 22, 23 S., R. 44 E., Malheur County | Sampling and geophysics by Noranda, mapping by Echo Bay. |

Table 3. *Exploration sites in Oregon, 1990 (continued)*

| No. | Mine name | Company | Commodity | Location | Remarks |
|---|---|---|---|---|---|
| 27 | Camp Kettle | ASARCO, Inc. | Lode gold | T. 23 S., R. 45 E., Malheur County | Geologic mapping and geochemical sampling. |
| 28 | Dry Creek Buttes area | Manville Corporation and ASARCO, Inc., Noranda Expl., Inc. | Lode gold | Tps. 23, 24 S., Rs. 43, 44 E., Malheur County | Drilling, surface sampling, and geophysics by Noranda; geologic mapping and geochemistry by ASARCO. |
| 29 | Jessie Page (Quartz Mtn.) | Chevron Resources Co. and M.K. Gold | Lode gold | Sec. 6, T. 25 S., R. 43 E., Malheur County | About 140 drill holes. |
| 30 | Red Butte | Chevron Resources Company | Lode gold | Secs. 26, 27, 34, 35, T. 25 S., R. 43 E., Malheur County | Hand sampling and trenching. |
| 31 | South Owyhee Ridge area | Manville Corporation and ASARCO, Inc.; Noranda Exploration, Inc., and Euro-Nevada Minerals joint venture | Lode gold | Tps. 24, 25 S., R. 45 E., Malheur County | ASARCO ran geophysics and drilled 9 holes at Katey; Noranda Exploration did surface sampling, geophysics, geochemistry, and drilling at Goldfinger. |
| 32 | Bannock | Manville Corporation | Lode gold | Sec 11, T. 26 S., R. 46 E., Malheur County | Drilled one hole, geochemical sampling. |
| 33 | Mahogany | Chevron Resources Company, leased from Manville Corp. | Lode gold | Secs. 25, 26, T. 26 S., R. 46 E., Malheur County | Drilled two holes. |
| 34 | Mahogany Gap and Storm | Phelps Dodge | Lode gold | Secs. 18, 19, 30, T. 27 S., R. 45 E., Malheur County | 39 claims; drilling and hand sampling. |
| 35 | Jordan Valley area | Manville Corporation, Battle Mountain Expl. Co., Nerco Expl. Co. | Lode gold | T. 29 S., R. 45 E., Malheur County | Geologic mapping and geophysics at Manville's Hillside prospect; drilling and geophysics at Battle Mountain's Lava Project. |
| 36 | Stockade area | BHP-Utah International, Carlin Gold jt. venture; Phelps Dodge | Lode gold | Tps. 25, 26 S., R. 38 E., Malheur County | 44 claims; drilling and hand sampling by Phelps Dodge. BHP-Utah International drilled 18 holes at Stockade Mountain. |
| 37 | Drewsey area (Red Butte/Pine Creek) | Battle Mountain Expl. Company and others | Lode gold | T. 20 S., R. 35 E., Harney County | Battle Mountain permitted to drill at Pine Creek. |
| 38 | Baboon Creek | Chemstar Lime, Inc. | Limestone | T. 19 S., R. 32 E., Grant County | Drilled 2 holes. |
| 39 | Idol City area | Newmont Exploration, Ltd. | Lode gold | Tps. 20, 21 S., R. 32 E., Harney County | Drilled during 1989. |
| 40 | Bear Creek Butte | Coeur d'Alene Mining | Lode gold | Tps. 18, 19 S., R. 18 E., Crook County | Geologic mapping and surface sampling, aero-mag. |
| 41 | Glass Butte | Galactic Resources | Lode gold | Tps. 23, 24 S., R. 23 E., Lake County | Drilled during 1989. |
| 42 | Summer Lake area | N.A. Degerstrom, Inc. | Lode gold | Sec. 14, T. 30 S., R. 16 E., Lake County | Drilling and surface geochemistry. |
| 43 | Paisley area | N.A. Degerstrom, Inc.; Atlas Pr. Metals, Inc. | Lode gold, perlite | T. 34 S., Rs. 18, 19 E., Lake County | Degerstrom drilled 4 holes, did soil sampling, VLF resistivity, and magnetics; Atlas drilled perlite prospect at Tucker Hill. |
| 44 | Quartz Mountain | Pegasus Gold, Inc.; Quartz Mountain Gold Corporation; Wavecrest Resources | Lode gold | Secs. 26, 27, 34, 35, T. 37 S., R. 16 E., Lake County | Drilled 28 development holes and 19 large-diameter core holes; pilot metallurgy; 9.8 million tons grading 0.045 oz/ton gold and 64 million tons grading 0.025 oz/ton gold. |
| 45 | Bohemia District (Grouse Mtn./ Noonday Ridge prospects) | Bond Gold Exploration, Inc. | Lode gold | T. 22 S., Rs. 1, 2 E., Lane County | Geologic mapping, trenching, geophysics, dropped property. |
| 46 | Prospect Silica (Quartz Mountain / Abbott Butte) | Mountain Valley Resources | Silica | T. 30 S., R. 2 E., Jackson and Douglas Counties | Hand sampling and feasibility studies. |
| 47 | Martha Mine | Cambiex and Dragon's Gold, joint venture | Lode gold | Sec. 28, T. 33 S., R. 5 W., Josephine County | Cored 3,000 ft in 4 holes; soil sampling. |
| 48 | Marble Mountain | Campman Calcite | Limestone | Sec. 19, T. 37 S., R. 6 W., Josephine County | Road work, feasibility study. |
| 49 | Eight Dollar Mountain | Geoff Garcia | Nickel laterite | T. 38 S., R. 8 W., Josephine County | Sampling. |
| 50 | Turner-Albright | Cominco | Copper, zinc, gold | Secs. 15, 16, T. 41 S., R. 9 W., Josephine County | — |

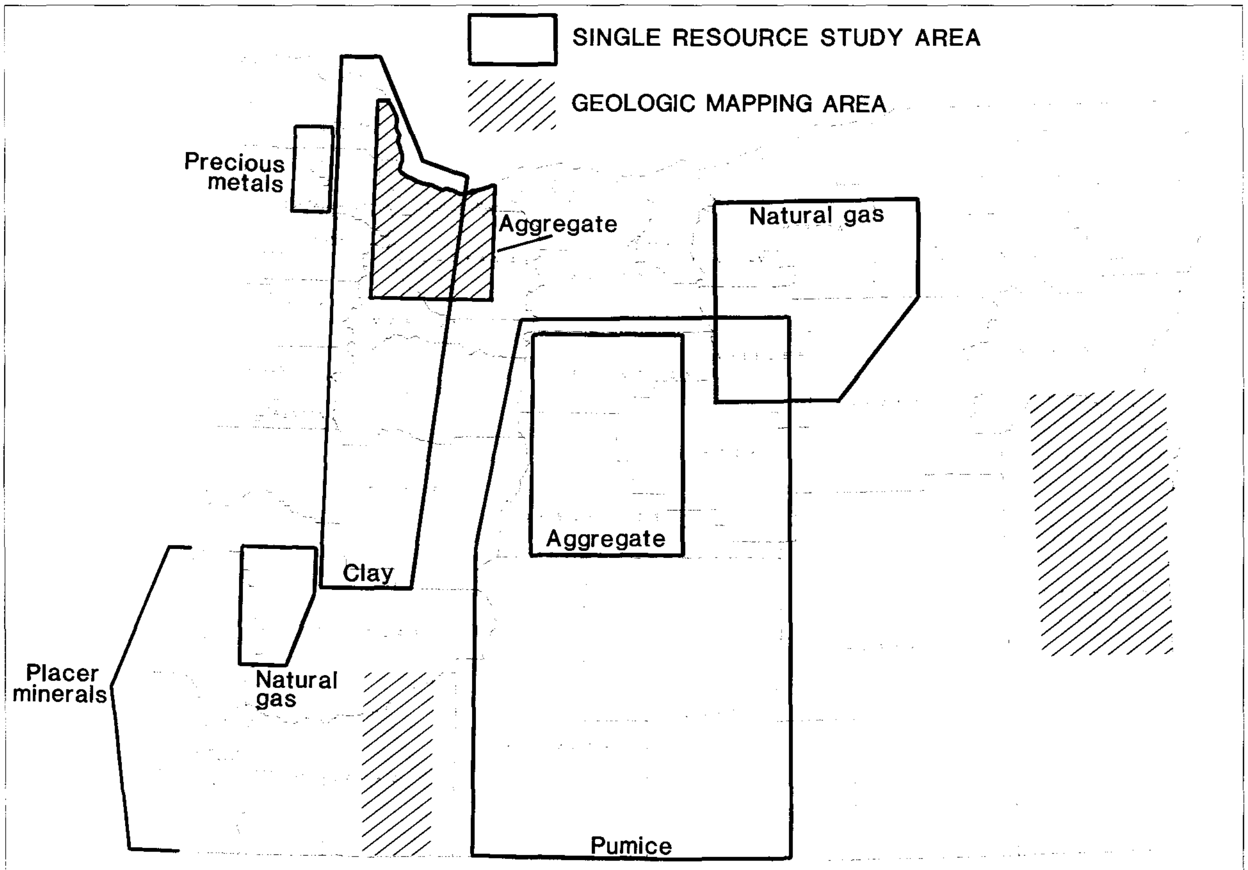



*Figure 4. Areas of ongoing or planned mapping and commodity studies by the Oregon Department of Geology and Mineral Industries.*

**Western Oregon**

Plexus Resources Corporation drilled 16 new core holes at the Bornite copper-gold-silver prospect (Exploration site 7, Table 3) in Marion County. This brings the number of holes to 29 for a total drilled thickness of 21,403 ft. The ore body is a breccia pipe 400 ft in diameter and 850 ft deep. Based on the work completed this year, reserves should increase from earlier estimates of 2.8 million tons copper grading 2.44 percent, 0.02 oz/ton gold, and 0.58 oz/ton silver at a 1-percent copper cutoff. Highest grades occur at the perimeter of the deposit.

Bond Gold evaluated the Grouse Mountain and Noonday Ridge prospects (Exploration site 45, Table 3) near the Helena Mine in Lane County's Bohemia Mining District and dropped the properties.

Cambiex and Dragon's Gold began a 10,000-ft core-drilling project at the Martha Mine in Josephine County's Greenback District (Exploration site 47, Table 3). Four holes were completed for a total of 3,000 ft, each intercepted the primary vein. More than 900 ft of tunnel was completed on two levels and 100,000 tons of 0.3 oz/ton ore have been blocked out along a 6-ft-wide vein.

Cominco is beginning a project at the Turner-Albright copper, zinc, and gold prospect (Exploration site 50, Table 3) in southern Josephine County. The company has plans for a geophysics program. Metallurgical problems have stymied development in the past, and Cominco brings considerable expertise to bear on the problem.

**DOGAMI research**

The Department is currently conducting geologic mapping projects in Malheur, Jackson, and Douglas Counties and in the Portland area. These projects should provide new insights into the distribution and occurrence of mineral resources. Regional studies emphasizing single commodities including talc, limestone, bentonite, and silica have been published during the last three years. Studies of pumice, strategic minerals, natural gas, aggregate, clay, and precious metals are planned for the next six years (Figure 4).

**ACKNOWLEDGMENT**

I would like to thank the many geologists and corporations that provided the information contained in this report. □

## Mist Gas Field Report revised

The Mist Gas Field Report published by the Oregon Department of Geology and Mineral Industries (DOGAMI) has been revised and is now available with all 1990 activity and changes included.

This report includes the Mist Gas Field Map, which was revised to show the three wells drilled by Nehama and Weagant Energy Company and the two service wells drilled by Northwest Natural Gas Company during the year. The location, status, and depth of all wells are indicated on the map.

The report also includes production figures for the wells at Mist from the initial production in 1979 through the end of 1990. Included are well names, revenue generated, pressures, annual and cumulative production, and other data.

The Mist Gas Field Report, Open-File Report 0-91-1, is now available at the DOGAMI office, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. The price is $8. See further ordering instructions on the last page of this issue.□

# MINERAL EXPLORATION ACTIVITY

## MAJOR MINERAL-EXPLORATION ACTIVITY

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Baker 1990 | Baboon Creek Chemstar Lime, Inc. | T. 19 S. R. 38 E. | Lime-stone | App |
| Baker 1990 | Cracker Creek Mine Bourne Mining Co. | T. 8 S. R. 37 E. | Gold | Expl |
| Baker 1991* | Gold Ridge Mine Golconda Resources | T. 12 S. R. 43 E. | Gold | App |
| Crook 1988 | Bear Creek Freeport McMoRan | Tps. 18, 19 S. R. 18 E. | Gold | Expl |
| Grant 1990 | Prairie Diggings Western Gold Explor. | T. 13 S. R. 32 E. | Gold | Expl |
| Grant 1991* | Bear Creek Project Coeur Explorations. | T. 18 S. R. 18 E. | Gold | App |
| Harney 1990 | Pine Creek Battle Mtn. Explor. | T. 20 S. R. 34 E. | Gold | Expl |
| Jefferson 1991* | Red Jacket Bond Gold | Tps. 9, 10 S. R. 17 E. | Gold | App |
| Josephine 1990 | Martha Property Cambiex USA, Inc. | T. 33 S. R. 5 W. | Gold | App |
| Lake 1988 | Quartz Mountain Wavecrest Resources. | T. 37 S. R. 16 E. | Gold | Expl |
| Lake 1990 | Glass Butte Galactic Serives, Inc. | Tps. 23, 24 S. R. 23 E. | Gold | Expl |
| Lane 1990 | Grouse Mtn. Project Bond Gold Exploration | T. 23 S. Rs. 1, 2 E. | Gold | Expl |
| Malheur 1988 | Grassy Mountain Atlas Precious Metals | T. 22 S. R. 44 E. | Gold | Expl, com |
| Malheur 1988 | Harper Basin Project Amer. Copper & Nickel | T. 21 S. R. 42 E. | Gold | Expl |
| Malheur 1988 | Jessie Page Chevron Resources Co. | T. 25 S. R. 43 E. | Gold | Expl |
| Malheur 1988 | Kerby Malheur Mining | T. 15 S. R. 45 E. | Gold | Expl, com |
| Malheur 1989 | Hope Butte Chevron Resources Co. | T. 17 S. R. 43 E. | Gold | Expl, com |
| Malheur 1990 | Ali/Alk Atlas Precious Metals | T. 17 S. R. 45 E. | Gold | App |
| Malheur 1990 | Buck Gulch Teague Mineral Prod. | T. 23 S. R. 46 E. | Ben-tonite | Expl |
| Malheur 1990 | Calavera NERCO Exploration | T. 21 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Cow Valley Butte Cambiex USA, Inc. | T. 14 S. R. 40 E. | Gold | Expl |
| Malheur 1990 | Freezeout Western Mining Corp. | T. 23 S. R. 42 E. | Gold | Expl |
| Malheur 1990 | Goldfinger Site Noranda Exploration | T. 25 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Grassy Mtn. Regional Atlas Precious Metals | T. 22 S. R. 44 E. | Gold | App |
| Malheur 1990 | Katey Claims Asarco, Inc. | Tps. 24, 25 S. Rs. 44, 46 E. | Gold | Expl |
| Malheur 1990 | KRB Placer Dome U.S. | T. 25 S. R. 43 E. | Gold | App |
| Malheur 1990 | Lava Project Battle Mtn. Explor. | T. 29 S. R. 45 E. | Gold | Expl |

MAJOR MINERAL-EXPLORATION ACTIVITY (continued)

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Malheur 1990 | Mahogany Project Chevron Resources Company | T. 26 S. R. 46 E. | Gold | App |
| Malheur 1990 | Racey Project Billiton Minerals USA | T. 13 S. R. 41 E. | Gold | Expl |
| Malheur 1990 | Sand Hollow Noranda Exploration | T. 24 S. R. 43 E. | Gold | Expl |
| Malheur 1990 | Stockade Mountain BHP-Utah International | T. 26 S. Rs. 38, 39 E. | Gold | Expl |
| Malheur 1990 | Stockade Project Phelps Dodge Mining Company | Tps. 25, 26 S. R. 38 E. | Gold | App |
| Malheur 1991* | Rhinehardt Site Atlas Precious Metals | Tps. 18, 19 S. R. 45 E. | Gold | Expl |
| Malheur 1991* | White Mountain D.E. White Mtn. Mining and Manufacturing | T. 18 S. R. 41 E. | Dia-toms | App |
| Marion 1990 | Bornite Project Plexus Resources Corporation | T. 8 S. R. 3 E. | Copper | App |

Explanations: App=application being processed. Expl=Exploration permit issued. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. *=New site

### Status changes

During January and February, three exploration permits were closed and five new ones were opened. The new sites are denoted by an asterisk (*) adjacent to the year. Three sites were inadvertently omitted from the list in March, they are returned to the list.

The files that were closed include the following: (1) The Kappes Cassiday Susanville project, where reclamation has been completed; (2) the Malheur Mining East Ridge application, which was incorporated into the permit area for the Kerby project; and the Carlin Gold Company South Star application, which was withdrawn before any work was done on the site.

The permit area of the Atlas Snake Flat permit was increased, and the name was changed to Grassy Mountain Regional to reflect this change.

An application for a bulk sample to conduct metallurgical testing by Atlas Precious Metals at its Grassy Mountain Project is being reviewed. The agency will provide public input opportunity prior to any permit decision.

Doug Smith has submitted an application for a small nickel surface mine on Eight Dollar Mountain in Josephine County.

### Regulatory issues

Numerous bills relating to the regulation of mining have been introduced in the state legislature. Most bills target large-scale, open-pit gold mining in southeastern Oregon where cyanide is to be used in the recovery process. Governor Roberts has convened a Governor's Mine Work Group consisting of members from industry, the environmental community, and state regulatory agencies to try to identify areas of consensus for a comprehensive mine regulatory program for the State of Oregon.

Questions or comments about exploration activities in Oregon should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office, 1534 SE Queen Avenue, Albany OR 97321, telephone (503) 967-2039. □

# AVAILABLE DEPARTMENT PUBLICATIONS

## GEOLOGICAL MAP SERIES

| | | Price | √ |
|---|---|---|---|
| GMS-4 | Oregon gravity maps, onshore and offshore. 1967 | 4.00 | |
| GMS-5 | Geologic map, Powers 15-minute Quadrangle, Coos/Curry Counties. 1971 | 4.00 | |
| GMS-6 | Preliminary report on geology of part of Snake River canyon. 1974 | 8.00 | |
| GMS-8 | Complete Bouguer gravity anomaly map, central Cascade Mountain Range. 1978 | 4.00 | |
| GMS-9 | Total-field aeromagnetic anomaly map, central Cascade Mountain Range. 1978 | 4.00 | |
| GMS-10 | Low- to intermediate-temperature thermal springs and wells in Oregon. 1978 | 4.00 | |
| GMS-12 | Geologic map of the Oregon part of the Mineral 15-minute Quadrangle, Baker County. 1978 | 4.00 | |
| GMS-13 | Geologic map, Huntington and parts of Olds Ferry 15-minute Quadrangles, Baker and Malheur Counties. 1979 | 4.00 | |
| GMS-14 | Index to published geologic mapping in Oregon, 1898-1979. 1981 | 8.00 | |
| GMS-15 | Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981 | 4.00 | |
| GMS-16 | Free-air gravity and complete Bouguer gravity anomaly maps, south Cascades, Oregon. 1981 | 4.00 | |
| GMS-17 | Total-field aeromagnetic anomaly map, southern Cascades, Oregon. 1981 | 4.00 | |
| GMS-18 | Geology of Rickreall/SalemWest/Monmouth/Sidney 7½-minute Quadrangles, Marion/Polk Counties. 1981 | 6.00 | |
| GMS-19 | Geology and gold deposits map, Bourne 7½-minute Quadrangle, Baker County. 1982 | 6.00 | |
| GMS-20 | Geology and geothermal resources, S½ Burns 15-minute Quadrangle, Harney County. 1982 | 6.00 | |
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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

## Cover photo

Green calcareous paleosols of the Turtle Cove Member of the John Day Formation, Foree Unit, John Day Fossil Beds National Monument.

The area of the John Day Fossil Beds National Monument in Wasco County, Oregon, is a major point of interest in the field trip guide beginning on the next page.

# OIL AND GAS NEWS

### Oil and gas leasing activity

During April, Columbia County held an oil and gas lease sale at which Nehama and Weagant Energy Company of Bakersfield, California, acquired three leases consisting of 677 acres located in the Mist Gas Field. All were purchased for $2.50 per acre. The State of Oregon held an oil and gas lease sale during May, at which Nehama and Weagant acquired three leases comprising 897 acres located in Clatsop County, adjacent to the Mist Gas Field. All were purchased for $1.00 per acre. The USDA Forest Service plans to hold an oil and gas lease sale for acreage in the Ochoco National Forest in central Oregon. Details can be obtained from Deborah Tout, Ochoco National Forest, P.O. Box 490, Prineville, Oregon 97754.

### NWPA annual symposium scheduled

The annual field symposium of the Northwest Petroleum Association (NWPA) will be held September 8-10 and will discuss the geology and petroleum potential of the Bellingham Basin, northwestern Washington and southwestern British Columbia. The symposium will include talks and presentations and a day in the field. Contact the NWPA, P.O. Box 6679, Portland, Oregon 97228-6679, for further information.

### Recent permits

| Permit no. | Operator, well, API number | Location | Status, proposed total depth (ft) |
|---|---|---|---|
| 452 | Nehama & Weagant<br>Columbia Co. 23-35-75<br>36-009-00278 | SW¼ sec. 35<br>T. 7 N., R. 5 W.<br>Columbia County | Permit;<br>3,400. |
| 453 | Nehama & Weagant<br>Columbia Co. 42-3-65<br>36-009-00279 | NE¼ sec. 3<br>T. 6 N., R. 5 W.<br>Columbia County | Permit;<br>3,300. |
| 454 | Nehama & Weagant<br>Columbia Co. 22-2-65<br>36-009-00280 | NW¼ sec. 2<br>T. 6 N., R. 5 W.<br>Columbia County | Permit;<br>3,000. |
| 455 | Nehama & Weagant<br>Columbia Co. 14-32-75<br>36-009-00281 | SW¼ sec. 32<br>T. 7 N., R. 5 W.<br>Columbia County | Permit;<br>3,500. |
| 456 | Nehama & Weagant<br>Adams 31-34-75<br>36-009-00282 | NE¼ sec. 34<br>T. 7 N., R. 5 W.<br>Columbia County | Permit;<br>3,600. |
| 457 | Nehama & Weagant<br>Columbia Co. 23-31-65<br>36-009-00283 | SW¼ sec. 31<br>T. 6 N., R. 5 W<br>Columbia County | Application;<br>2,340. |
| 458 | Nehama & Weagant<br>Columbia Co. 34-31-65<br>36-009-00284 | SE¼ sec. 31<br>T. 6 N., R. 5 W.<br>Columbia County | Application;<br>2,110. |
| 459 | Nehama & Weagant<br>Columbia Co. 44-8-64<br>36-009-00285 | SE¼ sec. 8<br>T. 6 N., R. 4 W.<br>Columbia County | Application<br>1,870 |
| 460 | Nehama & Weagant<br>LF 21-31-65<br>36-009-00286 | NW¼ sec. 31<br>T. 6 N., R. 5 W.<br>Columbia County | Application;<br>1,950. |
| 461 | Nehama & Weagant<br>CER 14-26-64<br>36-009-00287 | SW¼ sec. 26<br>T. 6 N., R. 4 W.<br>Columbia County | Application;<br>2,850 |

□

# A field guide to mid-Tertiary paleosols and paleoclimatic changes in the high desert of central Oregon—Part 2

*by Gregory J. Retallack, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403*

This field trip guide was prepared for the Theme Meeting of SEPM (Society for Sedimentary Geology) to be held August 15-18, 1991, in Portland, Oregon. The theme of this meeting is "Continental margins—sedimentation, tectonics, eustasy, and climate." Part 1 of the guide for the two-day field trip appeared in the last (May 1991) issue of *Oregon Geology* and ended with the return to John Day to spend the night. This second part presents the guide for the second day and the conclusion of the paper. *—Editor*

## EXCURSION ITINERARY FOR SECOND DAY

Leave John Day heading west on U.S. Highway 26. The valley of the John Day River is flanked to the south by Triassic and Jurassic schists and to the north by a Miocene and Pliocene sequence of white to gray silty claystones and volcanic ashes, within which the Rattlesnake ash-flow tuff forms a prominent scarp. Picture Gorge Basalt in a gorge south of the highway at a point 16 mi west of John Day has yielded a K-Ar age of 15.8 m.y. (Evernden and others, 1964, corrected by method of Dalrymple, 1979). The overlying gray to brown, clayey Mascall Formation is also middle Miocene in age. The prominent rhyodacitic ash-flow tuff of the Rattlesnake Formation in this area has a corrected radiometric age of 6.6 m.y., so that the tuffaceous sediments enclosing it are late Miocene and Pliocene in age. This ash-flow tuff represents a catastrophic volcanic event and is here over 100 mi distant from its source in the Harney Basin south of Burns (Oles and others, 1973).

In the river bank near the roadside rest stop that is immediately west of the bridge across the John Day River about 11 mi west of Mount Vernon is a locality for fossil leaves in the middle Miocene Mascall Formation (Chaney, 1948; Chaney and Axelrod, 1959). The ten most common species at this locality, comprising 78 percent of the flora, are (in order of decreasing abundance): Swamp cypress (*Taxodium distichum*), black oak (*Quercus pseudolyrata*), hickory (*Carya bendirei*), sycamore (*Platanus dissecta*), black oak (*Quercus merriami*), maple (*Acer bolanderi*), redwood (*Sequoia heerii*), maidenhair tree (*Ginkgo adiantoides*), box elder (*Acer negundoides*), and elm (*Ulmus speciosa*). This mixed broadleaf and conifer assemblage is an indication of cool-temperate, seasonal conditions. Paleoclimate was still very different from the high-desert climate of the present day and was more like the present-day climate of southern Indiana or Ohio. By using foliar physiognomic data from the Mascall flora, Wolfe (1981b) estimated a mean annual temperature of 9° to 10 °C and a mean annual range of temperature of 12° to 23 °C. Winters may have been consistently snowy by this time.

About 4 mi west of Dayville on Highway 26, look for and turn onto an unsealed road leading southwest onto the high terrace.

### STOP 9. Picture Gorge overlook

One-half mile south of U.S. Highway 26 on Day Creek Road, 4 mi west of Dayville (NE¼NE¼ sec. 29, T. 12 S., R. 26 E., Picture Gorge 15-minute quadrangle), we find a spectacular view of Picture Gorge and overlying sedimentary rocks (Figure 6). The Gorge itself is formed of tholeiitic flood basalts of the middle Miocene Picture Gorge Basalt of the Columbia River Basalt Group. Here the flows dip to the southeast and have been deeply incised by the John Day River, which was an antecedent stream to this tectonic deformation. Although the scene makes a fine photograph, this is not the origin of the name Picture Gorge: that name is based on the early discovery of Indian pictographs within the gorge.

Overlying the basalt with a slight angular discordance is a thick sequence of gray and brown tuffaceous alluvial sediments of the Miocene Mascall Formation. In places, diffuse dark layers of paleosols and light-colored, prominently outcropping sandstones of paleochannels can be seen. The formation onlaps tilted basalts, so that some deformation had been initiated during Miocene time. The blocky, mesa-forming unit overlying the Mascall Formation is welded tuff of the Pliocene Rattlesnake Formation. It onlaps the Mascall Formation with an angular discordance that resulted from continued Pliocene tilting.

Just over the bank here, in the Mascall Formation, Downs (1956, highway locality) reported fossil mammal remains including three-toed horse (*Merychippus seversus*) and pronghorn antelope (*Blastomeryx, Dromomeryx*) typical of middle Miocene faunas (Barstovian North American land mammal "age"). These are considered grassland-adapted mammals because of their high-crowned teeth and elongate limbs with hard hooves. Such open vegetation is also indicated by the thin, gray, calcareous paleosols visible in badlands of the

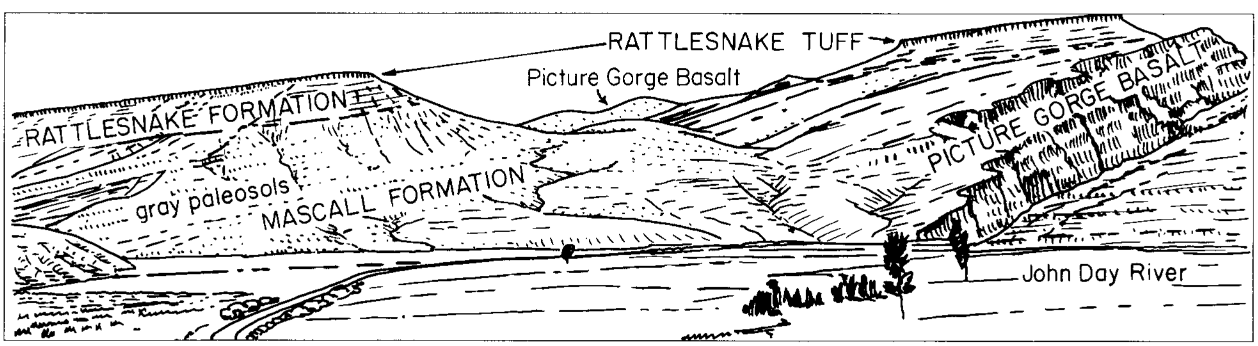


*Figure 6. Geological sketch of Picture Gorge, viewed from the east.*

Mascall Formation to the west, although it would not have been suspected from the Mascall flora already discussed from east of Dayville (Chaney, 1948). That broadleaf forest and swamp vegetation was probably widespread around lowland lakes and streams, and its fossil leaves accumulated and were preserved in them. On dry, grassy parts of the landscape, however, plant material decayed in the oxidized, calcareous soil where bones of animals accumulated.

The Rattlesnake Formation in Cottonwood Creek to the west also has yielded fossil mammals (Merriam and others, 1925), principally one-toed grazing horses (*Pliohippus spectans*) and three-toed horses (*Cormohipparion occidentale*) of late Miocene age (Hemphillian land mammal "age").

### En route

Return to Highway 26 and continue west into Picture Gorge.

### STOP 10. Picture Gorge Basalt and paleosols

Road cuts 0.5 mi northwest of the entrance to Picture Gorge (NW¼SW¼ sec. 17, T. 12 S., R. 26 E., Picture Gorge 15-minute quadrangle) show prominent red paleosols dividing flows of the Picture Gorge Basalt of the middle Miocene Columbia River Basalt Group. Red paleosols are widespread between flows in this area and allow flows to be distinguished readily. The paleosol profile just above road level is almost 2 m thick and appears to have been developed on a scoriaceous upper portion of the flow. The top of the profile is clayey and contains sparse root traces and strongly weathered fragments of basaltic scoria. This kind of clayey soil is formed over a considerable period of time (several tens of thousands of years) under woodland or forest in humid to subhumid climates (Retallack, 1990). Current radiometric estimates on the geological time represented by the Columbia River basalt allow periods on the order of 20,000 years between eruptions (Hooper and Swanson, 1990). These reddish interflow zones have been attributed entirely to baking of flow tops by the succeeding flow. While baking may have hardened and reddened the paleosols and added zeolites and other highly alkaline minerals to them, it is unlikely to have generated their clayey texture, soil structure, primary oxidation, root traces, and other weathering features.

### En route

Continue on Highway 26 until it turns off to the west; then follow Highway 19 to the north.

### STOP 11. Sheep Rock Overlook

Sheep Rock is a prominent conical hill, and an overlook is well signposted along Oregon Highway 19, north of its intersection with U.S. Highway 26 in Picture Gorge (NW¼NW¼ sec. 8, T. 12 S., R. 26 E., Picture Gorge 15-minute quadrangle). This hill is capped by middle Miocene Picture Gorge Basalt of the Columbia River Basalt Group (Figure 7). Also exposed is Oligocene to early Miocene John Day Formation, which is here divided into characteristically colored members (Fisher and Rensberger, 1972). These colors reflect paleosols of different paleoenvironments that have suffered different kinds of alteration after burial. The division of the John Day Formation into distinctly colored members as seen here is not possible in all locations where the formation crops out.

At the base of the exposed sequence along the river to the north are red claystones of the Big Basin Member of the John Day Formation. This is presumably early Oligocene in age, but only a fragment of entelodon jaw (*Archaeotherium*) has been reported at this stratigraphic level (Evernden and others, 1964). These red noncalcareous paleosols were not generally suitable for the preservation of bone. White bands interbedded with the red claystones are fresh beds of volcanic ash. These ashes represent the parent material of most of the paleosols of the John Day Formation, here oxidized to brown or red clay under former humid forest and probably reddened further by dehydration of ferric hydroxides (as commonly documented for paleosols; G.S. Smith, 1988; Retallack, 1990). As climate dried during the Oligocene and Miocene, this ash was less and less altered within soils under drier and sparser vegetation.

Above the red beds are the green calcareous claystones and siltstone of the Turtle Cove Member. As already discussed (Stop 8), fossil soils, mammals, snails, and hackberries at this stratigraphic level are evidence of a lowland mosaic of woodland and wooded grassland.

The prominent dark-brown unit halfway down the slope of Sheep Rock is a thick and extensive rhyolitic welded tuff. This represents a catastrophic eruption of a large ash-flow tuff from a vent in the Ochoco Mountains to the west (Robinson and others, 1984).

Buff-colored siltstones near the top of the sequence are the Kimberly Member of the John Day Formation. These alluvial deposits contain numerous brown calcareous paleosols, probably formed under a mosaic of woodland and wooded grassland.

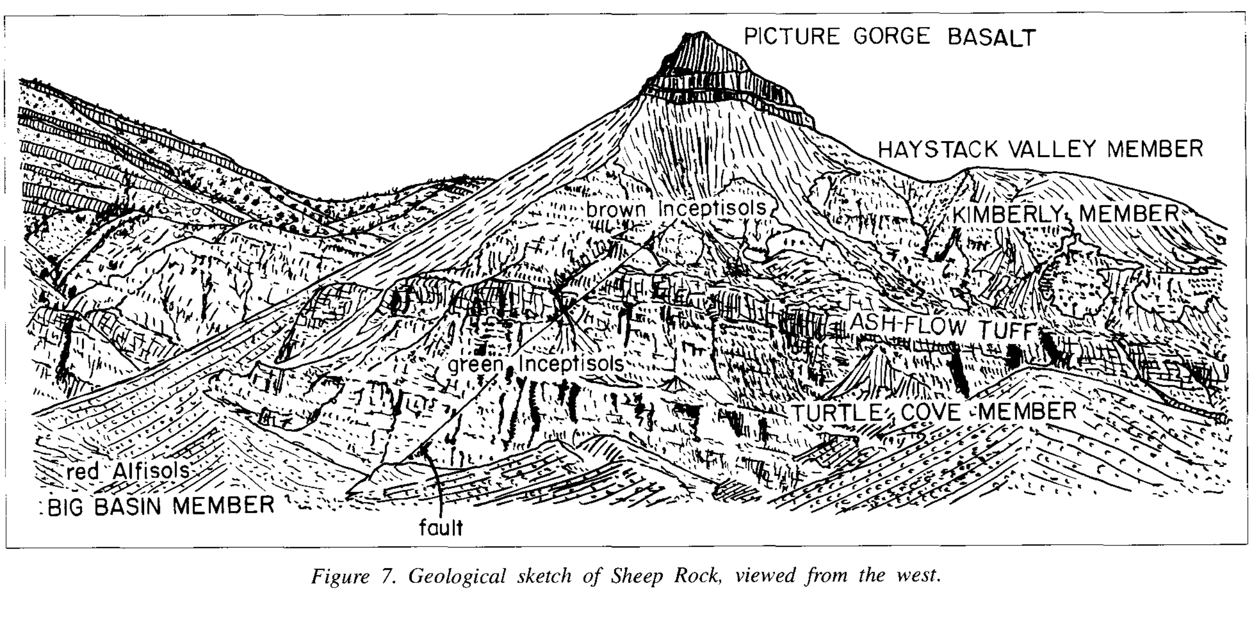


*Figure 7. Geological sketch of Sheep Rock, viewed from the west.*

The mammalian fauna of the Kimberly Member is diverse and includes hoglike oreodons (*Promerycochoerus superbus*), camels (*Paratylopus cameloides*), and tapirs (*Protapirus robustus*). This new fauna represents a significant advance in adaptations for open country, as in similar faunas in other areas of North America (Hunt, 1985) of early Miocene age (late Arikareean and Hemingfordian land mammal "ages"; Rensberger, 1983; Prothero and Rensberger, 1985).

**STOP 12. Cant Ranch Visitor Center**

North of Sheep Rock Overlook is the Visitor Center for John Day Fossil Beds National Monument at the old Cant Ranch (NE¼SW¼ sec. 6, T. 12 S., R. 26 E., Picture Gorge 15-minute quadrangle). Displays on the geology and paleontology of the mid-Tertiary sequence exposed in the John Day Valley and a fossil preparation laboratory are worth a visit. Maps and publications on the natural history of this region can be purchased here.

**En route**

Continue back south on Highway 19 into Picture Gorge, then west on U.S. Highway 26.

**STOP 13. Mascall paleosols**

A long, low road cut south of U.S. Highway 26, 2 mi west of its junction with Oregon Highway 19 (SE¼NE¼ sec. 24, T. 12 S., R. 25 E., Picture Gorge 15-minute quadrangle) reveals alluvial sediments and volcanic ash of the Miocene Mascall Formation. Remains of three-toed horse (*Merychippus seversus*) have been found in this formation 0.3 mi southwest of here (Rock Creek locality of Downs, 1956). White volcanic ash forms prominent, white bedded units, 3 m above the base of the cut. This ash was derived from Miocene volcanoes in the present area of the Western Cascades. Underlying the ash are three moderately developed paleosols (Inceptisols). They have thin (10 to 20 cm), yellowish-brown upper (A) horizons, with fine soil structure (granular peds of U.S. Department of Agriculture, 1975), over light-yellowish, weakly calcareous subsurface (Bk) horizons.

Calcareousness of the profiles is compatible with a subhumid climate. Their simple profile form and pattern of root traces are most like those found now under wooded grassland, a conclusion supported by dental and cursorial adaptation of mammal fossils found in the Mascall Formation. Topographic relief of these paleosols was probably low, but they show no mottles or restriction of rooting depth that might indicate waterlogging. Their parent material was air-fall ash from the Western Cascades mixed with rock fragments of local Mesozoic schists and sandstones. The time for formation of these paleosols was on the order of several thousands of years, considering the destruction of bedding in them and the fact that none show well-developed calcareous nodules.

**En route**

Some additional exposures of both the Mascall and Rattlesnake Formations can be observed in the hills to the west along U.S. Highway 26. Here, bluff and creek exposures of the Rattlesnake Formation have yielded the following fossil mammals (Merriam and others, 1925; MacFadden, 1984): Squirrel (*Spermophilus gidleyi*), single-toed horse (*Pliohippus spectans*), three-toed horses (*Cormohipparion occidentale* and *Hippotherium sinclairi*), rhinoceros (*Teleoceras* sp. cf. *T. fossiger*), peccaries (*Platygonus rex* and *Prosthennops* sp.), camel (Camelidae), bear (*Indarctos oregonensis*), and cat (Felidae).

Picture Gorge Basalt crops out 3.7 mi west of the junction of Highways 19 and 26 and includes a photogenic outcrop of columnar jointing. At a point 10 mi west of the junction, the road enters a narrow valley with exposures of lahars and flows of the Clarno Formation. As the road climbs up toward Keyes Summit, it passes upsection through Picture Gorge Basalt to Rattlesnake ash-flow tuff. Descending from Keyes Summit, the road passes down again through John Day Formation and then, in a number of large road cuts excavated in 1989, through magnificent series of volcanic breccias, plugs, and flows of the Clarno Formation.

Just west of Mitchell and north of the highway is Bailey Butte, a steeply-dipping andesite sill of the Clarno Formation. The sill intrudes the Hudspeth Formation, a middle Cretaceous (Albian to Cenomanian) marine shale. Ammonites (*Brewericeras hulensis* and *Leconteites lecontei*) can be found in calcareous nodules of the Hudspeth Formation a few miles north of here (Jones and others, 1965). The Hudspeth Formation interfingers with submarine fan conglomerates of the Gable Creek Formation in this area (Kleinhans and others, 1984).

Along U.S. Highway 26 and 3 mi west of Mitchell, look for a well-marked turnoff and take it north to the Painted Hills Unit of John Day Fossil Beds National Monument. At 2.4 mi north of Highway 26, the paved road to Painted Hills passes from Clarno Formation to the disconformably overlying John Day Formation, which includes an alkali olivine basalt 3.3 mi north of the highway.

The entrance to the Painted Hills Unit is southwest across Bridge Creek where the sealed road surface ends. Continue past the turnoff to the Visitors Center and into the colorful badlands, then turn south along a ridge to Lookout Point.

**STOP 14. Painted Hills Overlook**

From Lookout Point (SE¼NE¼ sec. 1, T. 11 S., R. 20 E., Painted Hills 7½-minute quadrangle) and several places on the way to it, spectacular outcrops of the color-banded, lower Oligocene Big Basin Member of the John Day Formation (Figure 8) are visible. The red bands are mainly subsurface (Bt) horizons of fossil soils of the kind formed under woodland (Alfisols). These interfinger with less developed, yellow fossil soils formed under open woodland and wooded grassland (Inceptisols) and also with fossil soils whose black subsurface horizons (iron manganese or placic horizons) formed in poorly drained parts of the landscape (gleyed Inceptisols).

Low on the hill 2 mi west of the lookout, numerous fossil plant remains have been collected at the type locality for assemblages called the "Bridge Creek Flora." This locality was discovered by Thomas Condon in 1865 (Clark, 1989) and subsequently studied in great detail by Ralph Chaney (Chaney, 1948) and Roland Brown (Brown, 1959). The fossil flora is generally similar to that examined in the John Day Formation behind the high school in Fossil (Stop 7). Wolfe (1981b) has estimated from foliar physiognomy of this flora that mean annual temperature was 11° to 12 °C, with a mean annual range of 22° to 24 °C.

The bluffs of John Day Formation to the north of the lookout are capped by the same extensive ash-flow tuff as seen at Sheep Rock (Stop 11). This tuff has been K-Ar dated near here at 25.9 m.y. (from Evernden and others, 1964, corrected by method of Dalrymple, 1979). Tuffs low in this bluff at a stratigraphic horizon 55 m above the base of the John Day Formation were dated at 31.9 m.y. (corrected from the same authors). Compared with outcrops of the stratigraphically equivalent Turtle Cove Member near Picture Gorge, few fossil mammals of the same kinds have been reported from here (T. Fremd, personal communication, 1991).

The brown badlands of the Kimberly Member and the white bluffs of the Haystack Member of the John Day Formation in the distance, under the long rampart of Columbia River basalt, have also yielded fossil mammals (of the late Arikareean and Hemingfordian land mammal "ages"). The lighter color, more calcareous composition, and less clayey texture of this part of the formation reflect less severe weathering in an increasingly dry climate. The middle Tertiary climatic deterioration of north-central Oregon is written prominently in paleosols of these scenic, color-banded badlands.

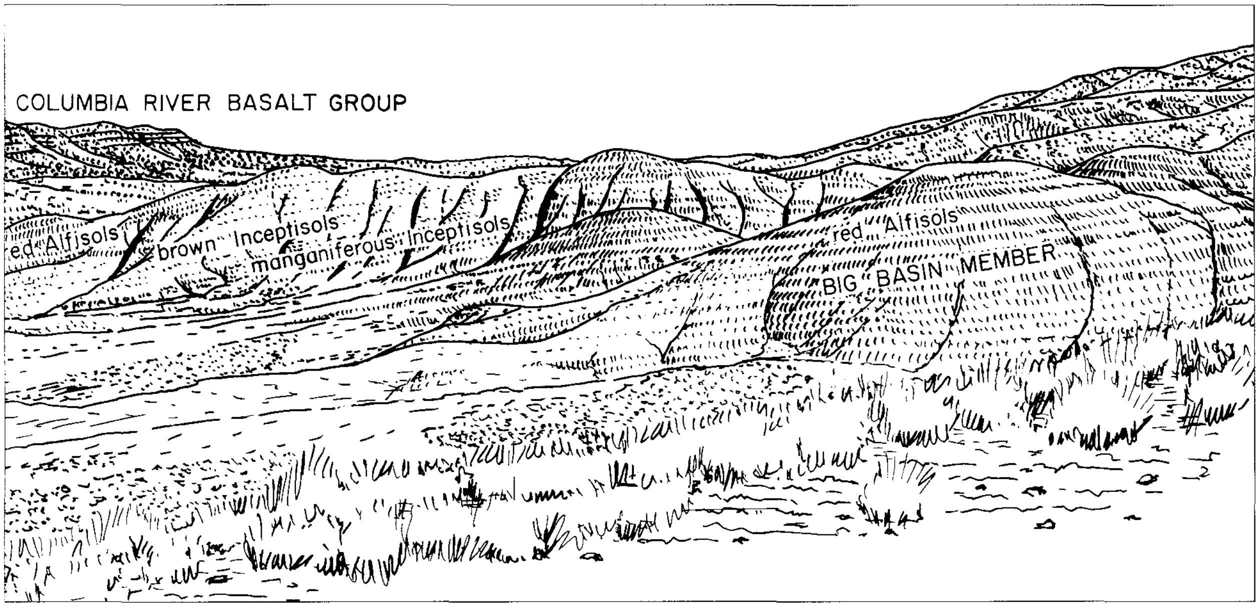


*Figure 8. Geological sketch of the Painted Hills Unit of the John Day Fossil Beds National Monument, viewed from the west.*

**En route**

Return south to U.S. Highway 26 and continue west toward Prineville. Ammonite-bearing Lower Cretaceous shales and sandstones of the Hudspeth Formation are exposed in road cuts low in the valley of Cherry Creek. These deposits of submarine fans are unconformably overlain by lacustrine and volcanic rocks of the Eocene Clarno Formation, which form the hills on either side of the road. The road cuts reveal more Clarno Formation as Highway 26 climbs toward Ochoco Summit.

**STOP 15. Clarno lake beds, Ochoco Summit**

Near the Ochoco National Forest boundary on the northeast side of Ochoco Summit, in a deep road cut on both sides of U.S. Highway 26 and 10 mi west of the Painted Hills turnoff (NW¼NW¼ sec. 17, T. 12 S., R. 20 E., Lawson Mountain 7½-minute quadrangle), occur black shales and gray, bedded sandstones of the Clarno Formation, intruded by a large sill of diabase containing veins of calcite, zeolites, and gabbro. The sill has uparched sediments in the central portion of the road cut, and there is a narrow chilled margin and zone of altered sediments. The sill is faulted against fluvial sandstones in the eastern portion of these road cuts.

The black shale is a deposit of a eutrophic lake. In an especially carbonaceous layer near road level are numerous scales and disarticulated skeletal debris of fish (Cavender, 1968), including remains of bowfins (cf. *Amia*), mooneyes (cf. *Hiodon*), catfish (aff. *Ictalurus*), and suckers (cf. *Amyzon*). These were large subtropical fish.

Overlying the lake deposits are alluvial sandstones and siltstones, in places with well-preserved fossil leaves, including viburnum (*Viburnum eocenicum*), cordia (*Cordia oregona*), and wingnut (*Pterocarya mixta*; all identified by the author). This fossil plant assemblage is similar to the late Eocene Goshen floras of the Willamette Valley (Chaney and Sanborn, 1933), from a time predating the Oligocene climatic deterioration and subsequent divergence in vegetation of western and eastern Oregon (Wolfe, 1981a). Paleosols in these alluvial deposits are limited to weakly developed profiles (Psamments) with fossil root traces and abundant relict bedding: an indication that these plants formed early successional vegetation of streamsides, again like the Goshen flora.

**En route**

Continue west over Ochoco Summit on U.S. Highway 26. Exposures of the Clarno Formation are poor in the drainage of Marks Creek. Past Ochoco Reservoir near Prineville, exposures of the basal ash-flow tuff of the John Day Formation occur. Closer to Prineville, the Rattlesnake ash-flow tuff forms a conspicuous ledge high on the hillsides. The rimrock on the skyline to the east and north of Prineville is the Madras flow of the Deschutes Formation. Prineville itself is built on Pleistocene lacustrine shales that were deposited when the Crooked River was dammed by intracanyon flows. These flows are well exposed in the gorge of the Deschutes River north of Redmond.

From Prineville, the road north toward Madras climbs between uplifted rocks of the John Day and Clarno Formations in Grizzly Butte to the east and Gray Butte to the west. The plateau over which the road approaches Madras provides excellent views on the skyline of Pliocene-Pleistocene volcanoes of the Cascade Crest: from the south, the Three Sisters, Mount Washington, Three Fingered Jack, and Mount Jefferson.

Return to Madras to conclude the second day of the field trip.

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ENTER THIS CONTEST TO NAME THE NATURAL RESOURCE AND OUTDOOR INFORMATION CENTER AND STORE OPENING FEBRUARY 1992 IN THE NEW STATE OFFICE BUILDING IN PORTLAND!

WIN A PIECE OF OREGON SUNSTONE JEWELRY!

**What is this new facility?** The State of Oregon Department of Geology and Mineral Industries will open a natural resource and outdoor information center and store on the ground floor of the new state office building in Portland, making available Department publications, materials from other state and federal natural resource agencies, U.S. Geological Survey topographic maps, and outdoor and interpretive types of literature from other sources. It will also provide computer access to natural resource and recreation data bases and serve as an Earth Science Information Center (ESIC) for the U.S. Geological Survey.

**We need** a short, wonderful name that will tell people exactly what our center and store is.

**To enter the contest,** send all entries in writing to Beverly F. Vogt, Oregon Department of Geology and Mineral Industries, 910 State Office Building, Portland, OR 97201. Five entries per letter or card will be accepted. Include name, address, and day phone number on each entry. Anyone is eligible, except for judges and their families.

**Deadline** is July 31, 1991, and all entries must be received by midnight of that date. Ties among entries will be broken on the basis of date received.

**Judging of entries** will be by a panel from natural resource agencies. Winners will be announced on August 24.

**Prize** will be a piece of Oregon Sunstone jewelry, a 40-percent discount on all purchases in the store for one year, and lots of publicity.

**Questions?** Call Beverly Vogt or Rhonda Moore at the Oregon Department of Geology and Mineral Industries, 229-5580.

# Geothermal exploration in Oregon, 1990

*by George R. Priest, Oregon Department of Geology and Mineral Industries*

## INTRODUCTION

Geothermal exploration activity decreased in 1990 relative to 1989. Only one hole was completed, and the amount of leased federal land and lease revenues continued to decline. The total amount of federal land leased for geothermal resources has declined steadily since the peak in 1983.

## DRILLING ACTIVITY AND RESULTS

Figure 1 shows the number of geothermal wells drilled and geothermal drilling permits issued from 1970 to 1990. Figure 2 shows the same information for geothermal prospect wells (depths <610 m). Table 1 lists the Oregon Department of Geology and Mineral Industries (DOGAMI) permits for geothermal drilling that were active in 1990. Six new permits were issued, all for geothermal wells. Drilling activity occurred on three holes, but only one was completed. California Energy Company (CEC) did some initial drilling on two locations in the volcanic highlands west of Bend. DOGAMI, working on a site near Santiam Pass, diamond-cored to 928 m on a hole rotary drilled in 1989 to 141 m.

One permit for geothermal prospect drilling was active: Permit 100, Anadarko Petroleum Corporation well 25-22A, Pueblo Valley area, Harney County. The well was suspended during 1990.

## LEASING

The amount of leased federal land and lease revenues, while still decreasing, stopped the steep slide that has occurred in previous years, changing by only a few percent from 1989 to 1990 (Table 2; Figures 3 and 4).

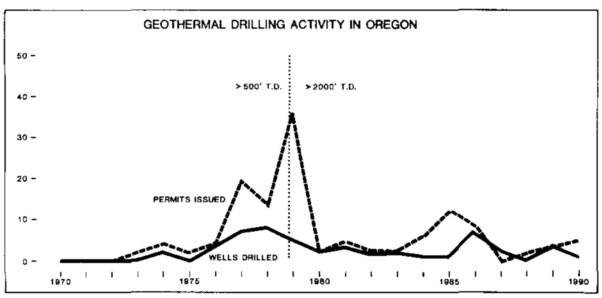


*Figure 1. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 610 m.*

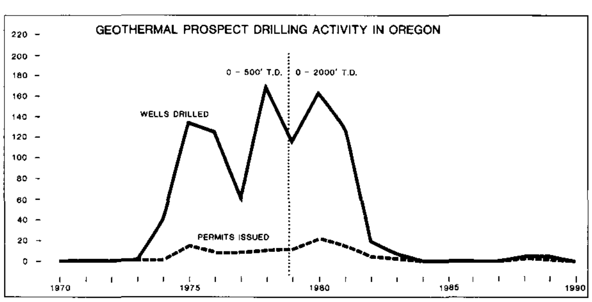


*Figure 2. Geothermal prospect well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth of less than 610 m.*

Table 1. *Active permits for geothermal drilling in 1990*

| Permit no. | Operator, well, API number | Location | Status, proposed total depth (m) |
|---|---|---|---|
| 116 | Calif. Energy Co. MZI-11A (deepening) 36-035-90014-80 | SW¼ sec. 10 T. 31 S., R. 7½ E. Klamath County | Suspended; confidential. |
| 117 | Calif. Energy Co. MZII-1 (deepening) 36-035-90015-80 | SE¼ sec. 13 T. 32 S., R. 6 E. Klamath County | Suspended; confidential. |
| 118 | GEO-Newberry N-1 36-017-90013 | SW¼ sec. 25 T. 22 S., R. 12 E. Deschutes County | Suspended; 1,387. |
| 125 | GEO-Newberry N-2 36-017-90018 | SW¼ sec. 29 T. 21 S., R. 12 E. Deschutes County | Suspended; confidential. |
| 126 | GEO-Newberry N-3 36-017-90019 | NE¼ sec. 24 T. 20 S., R. 12 E. Deschutes County | Suspended; 1,219. |
| 131 | GEO-Newberry N-4 36-017-90023 | NE¼ sec. 35 T. 21 S., R. 13 E. Deschutes County | Suspended; confidential. |
| 132 | GEO-Newberry N-5 36-017-90024 | NE¼ sec. 8 T. 22 S., R. 12 E. Deschutes County | Suspended; confidential. |
| 138 | GEO-Newberry NC54-5 36-017-90030 | NE¼ sec. 5 T. 22 S., R. 12 E. Deschutes County | Canceled. |
| 139 | Oxbow Power Corp. 77-24 36-031-90001 | SE¼ sec. 24 T. 13 S., R. 7½ E. Jefferson County | Suspended; 928. |
| 140 | Calif. Energy Co. MZI-9 36-035-90017 | SW¼ sec. 9 T. 31 S., R. 7½ E. Klamath County | Canceled. |
| 143 | Calif. Energy Co. CE-BH-4 36-017-90031 | SW¼ sec. 27 T. 16 S., R. 9 E. Deschutes County | Abandoned; confidential. |
| 144 | Anadarko Petroleum 52-22A 36-025-90004 | NE¼ sec.22 T. 37 S., R. 33 E. Harney County | Permitted; 762. |
| 145 | Anadarko Petroleum 66-22A 36-025-90005 | SE¼ sec. 22 T. 37 S., R. 33 E. Harney County | Permitted; 762. |
| 146 | Calif. Energy Co. MZI-1 36-035-90020 | NW¼ sec. 3 T. 30 S., R. 6 E. Klamath County | Permitted; 1,676. |
| 147 | Calif. Energy Co. CE-BH-7 36-017-90032 | NW¼ sec. 20 T. 17 S., R. 10 E. Deschutes County | Suspended; confidential. |
| 148 | Anadarko Petroleum 25-22A 36-025-90006 | SW¼ sec. 22 T. 37 S., R. 33 E. Harney County | Permitted; 762. |
| 149 | Calif. Energy Co. CE-BH-5 36-017-90033 | NW¼ sec. 25 T. 16 S., R. 9 E. Deschutes County | Permitted; 1,676. |

## KNOWN GEOTHERMAL RESOURCE AREA (KGRA) SALES

No KGRA lands were offered for bid in 1990. Some KGRA lands at Newberry volcano have been incorporated into a geological monument (see section on regulatory actions).

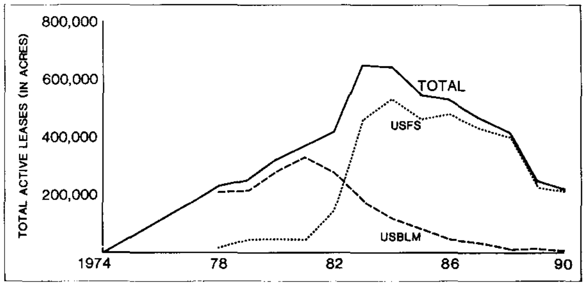


*Figure 3. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December 1990.*

## REGULATORY ACTIONS

Public Law 101-522, enacted November 5, 1990, created the Newberry Volcanoes National Monument. The monument area, combined with buffer zones of restricted access, encompasses about 85 percent of the land classified by the Federal Government as Known Geothermal Resource Area.

Anadarko Petroleum Corporation applied for permits to drill two new test wells near Borax Lake in the Alvord Desert area. Drilling is stalled pending review of appeals filed by various environmental organizations concerned about potential threats to the Borax Lake chub. In a related action, U.S. Representative Bob Smith introduced a bill to create an 812,870-acre Steens Mountain National Conservation Area. The bill failed to make it through Congress.

The Oregon Water Resources Department (WRD) wrote and amended administrative rules that addressed several geothermal issues pursuant to new legislation. The rules defined terms such as "thermal interference" or "substantial thermal alteration" and specified 65 °F as "a temperature below which low-temperature geothermal appropriations shall not be protected from thermal interference caused by ground-water appropriations for other purposes." Other provisions included injection well location, pump testing, and water analysis requirements.

WRD assisted in resolving a thermal-interference dispute near Vale. Two commercial users of low-temperature geothermal water reached a private agreement which avoided regulation by WRD.

## DIRECT-USE PROJECTS

The direct use of relatively low-temperature geothermal fluids continued in 1990 at about the same level as over the last several years. Most of the activity is centered in Klamath Falls and Vale.

### Ashland

Jackson Hot Springs in Ashland, Oregon, is still being run as a resort.

### Klamath Falls

The Klamath Falls district heating system is back on line after replacement of defective pipe connections. Nearly all of the water from the system is being reinjected.

### La Grande

The Hot Lake Recreational Vehicle Resort is utilizing 85 °C water from the Hot Lake artesian well to heat a pool and building. The company hopes to use the resource eventually to heat a fish-farming operation and to generate electricity.

### Lakeview

In Lakeview, the binary-cycle electrical generating station set up several years ago remains idle. The 300-kilowatt (kw) unit had an output of 250 kw from 105 °C water in a test performed November 18, 1982 (Geo-Heat Center Quarterly Bulletin, 1982).

### Paisley

The Paisley area has one of the best quality but least utilized low-temperature geothermal resources in the State. Thermal wells there reportedly have high flow rates (observations of Gerald L. Black, 1981) and temperatures as high as 111 °C at only 228 m (Oregon Department of Geology and Mineral Industries, 1982). A campground and recreational vehicle park utilizes hot water for a pool, but no other uses are known.

### Vale

In Vale, the Oregon Trail Mushroom Company, which commenced full-scale operations in 1986, continues to operate using water from a 107 °C aquifer for heating and cooling. Oregon Trail annually produces 2.3 million kilograms of mushrooms, which are marketed in Spokane, Seattle, Salt Lake City, and the Treasure Valley Area in Idaho (Geo-Heat Center Quarterly Bulletin, 1987). Other users at Vale include Ag-Dryers (a grain-drying facility) and a greenhouse operation.

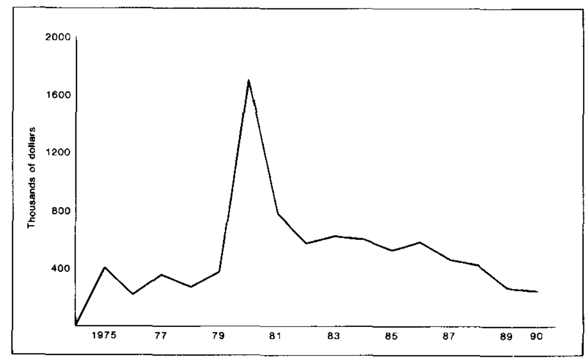


*Figure 4. Federal income from geothermal leases in Oregon from the inception of leasing in 1974 through December 1990.*

## USGS ACTIVITIES

The U.S. Geological Survey (USGS) continued its Cascade Range research of igneous processes, hydrothermally altered rock, thermal waters, hydrothermal systems, and regional geology. Charles Bacon's work was focused on the compilation of a preliminary geologic map of Mount Mazama at 1:24,000 scale (Bacon, 1990a). His other activities included electron microprobe analysis of minerals in postcaldera lavas and their xenoliths (Bacon and others, 1990), a study of pre-Mazama rhyodacite lavas that are exposed around (clockwise) the northeast to south edges of Mount Mazama, a study of volcanic rocks from the flanks of Mount Mazama (Bacon, 1990b), and the completion of rock chemistry for samples collected from the deep caldera walls with the submersible craft *Deep Rover*.

Keith Bargar and Terry Keith studied hydrothermal alteration in seven geothermal core holes drilled by GEO-Newberry Crater, Inc., and Santa Fe Geothermal, Inc., on the outer flanks of Newberry volcano (Bargar and others, 1990). The core from drill holes on the northern (GEO-N3), eastern (GEO-N4), southern (GEO-N1), and southwestern (GEO-N5) flank encountered temperatures below 100 °C and is only slightly altered. Measured temperatures in drill holes GEO-N2, SFNC 72-03, and SFNC-01 on the west flank of the volcano are as high as 170 °C, and the drill core is moderately altered. Fluid inclusion studies of core from the west flank drill holes and the two intracaldera drill holes USGS-N2 and RDO-1 indicate that past temperatures were above 300 °C near the western caldera ring fracture and at the bottom of USGS-N2. Fluid inclusion homogenization temperatures also are hotter at shallower depths in RDO-1, the intracaldera drill hole closest to the southern ring fracture. Bargar and Keith also continued their preparation of a draft report on hydrothermal alteration in the Mount Hood area. Steve Ingebritsen completed a summary paper on hydrothermal systems of the Cascade Range in north-central Oregon (Ingebritsen and others, in preparation).

By means of potassium-argon dating, Leda Beth Pickthorn continues to define the age of many previously undated volcanic units. Perhaps most intriguing is the evidence that most of the Dalles Formation was emplaced about 8-7 Ma; consequently, the Dalles Formation is substantially younger than the 14-11 Ma Rhododendron Formation, with which it was once correlated. Eleven new K-Ar age determinations from the Klamath Falls area indicate that almost all volcanic units once presumed to be Quaternary are in fact Pliocene and Miocene in age (Pickthorn and Sherrod, 1990).

Work continued at Mount Hood by both Water Resources and Geologic Division personnel. William Scott, Jim Vallance, and Tim Pierson concentrated on mapping and stratigraphic studies mainly of latest Pleistocene and Holocene pyroclastic-flow and debris-flow deposits in the Sandy River and its headwater tributaries. Bob Tilling began petrologic studies by collecting a suite of samples from numerous Mount Hood and pre-Mount Hood units. Dave Sherrod mapped much of the Dog River and Badger Lake quadrangles in order to better understand the Hood River fault and its relation to Mount Hood.

Cynthia Gardner and Andrei Sarna-Wojcicki (both USGS) have undertaken a cooperative study with Brittain Hill (Oregon State University) and Rob Negrini (California State University, Bakersfield) to bolster correlations of distal tephra and near-vent, middle Pleistocene pyroclastic deposits in the Bend area. The Bend pyroclastic deposits, which include air-fall and ash-flow tuffs such as the Bend Pumice, Desert Springs Tuff, and Tumalo Tuff, are presumably correlative with ash beds in some lake sediments from northern California, northern Nevada, and southern Oregon. The team is using paleomagnetic and geochemical techniques to strengthen the correlations, which will lead to a better understanding of the age of all these deposits.

## BONNEVILLE POWER ADMINISTRATION

In its 1990 Resource Program, the Bonneville Power Administration (BPA) offered to purchase, in joint ventures with regional utilities, 10 megawatts (MW) of output from each of three geothermal pilot projects in the Northwest. The main goal is to initiate development at three sites with potential for large-scale power production. Informal discussions with developers are underway, with letters of intent due September 3, 1991. Formal negotiations will begin on October 1, 1991.

To identify land use, environmental, and other issues associated with development and to provide a basis for informed resolution of these issues, several supporting activities are underway. It should be noted that although many of these activities focus on specific areas, they do not necessarily predict the locations of pilot projects.

The Oregon Department of Energy (ODOE) is performing studies to estimate the economic impact of a 100-MW geothermal project in Deschutes and Harney Counties. The Washington State Energy Office (WSEO) is doing similar studies for Skamania and Whatcom Counties. ODOE is also collecting data related to the operational and environmental records of existing U.S. geothermal plants.

Table 2. *Geothermal leases in Oregon in 1990*

| Types of leases | Numbers | Acres |
|---|---|---|
| Federal leases in effect: | | |
| Noncompetitive, USFS | 142 | 220,536.08 |
| Noncompetitive, USBLM | 2 | 942.79 |
| KGRA, USFS | 1 | 100.00 |
| KGRA, USBLM | 7 | 16,465.12 |
| Total leases issued: | | |
| Noncompetitive, USFS | 358 | 686,064.05 |
| Noncompetitive, USBLM | 266 | 406,157.79 |
| KGRA, USFS | 8 | 11,924.61 |
| KGRA, USBLM | 62 | 118,307.85 |
| Total leases relinquished: | | |
| Noncompetitive, USFS | 216 | 465,527.97 |
| Noncompetitive, USBLM | 264 | 405,215.00 |
| KGRA, USFS | 7 | 11,824.61 |
| KGR, USBLM | 55 | 101,842.73 |
| Lease applications pending | 121 | — |

The Deschutes National Forest, ODOE, and BPA are working together on a study to assess the land use impact of geothermal development in the Bend highlands area south of Sisters. The two federal agencies are also jointly funding a wide range of public-information and involvement activities related to geothermal development.

BPA is cooperatively funding designs of environmental baseline monitoring programs for several areas. The USGS Water Resources Division expects to begin collecting data this summer for a hydrologic network at Newberry volcano and the Alvord Desert. Design work will begin this year for programs to monitor air quality, flora, fauna, seismicity, and subsidence at Newberry.

The Geothermal Resources Council has received a grant to produce a report on environmental issues in geothermal development. The report will give authoritative nontechnical background on geothermal energy development and production. A document of this sort has long been needed to help answer the "most often asked" questions about geothermal energy.

Under a BPA contract, the WSEO will complete a series of guides to the regulatory process for renewable resources. The agency will also conduct a workshop on geothermal concerns for utilities and overseeing agencies.

The Electric Power Research Institute (EPRI), which receives funding from BPA, has produced guidebooks on "Geothermal Power Plant Selection" and on "Sampling and Analysis of Geothermal Fluids." BPA and EPRI are jointly funding efforts by the University of Hawaii to reduce resource confirmation costs. Project completion is expected in late 1991.

## DOGAMI APPLIED RESEARCH

The Oregon Department of Geology and Mineral Industries (DOGAMI) formulated a scientific drilling program in 1987 (Priest and others, 1987). Funding to support the program was found in 1989 from contributions of $200,000 by the U.S. Department of Energy (USDOE) and $100,000 by Oxbow Power Corporation (OPC). A hole was rotary drilled, and casing was set to 141 m in 1989 near Santiam Pass (Figures 5 and 6). In 1990, the hole was diamond cored to about 928 m, and geologic and geophysical data were collected.

Analysis of geophysical and geologic data from this hole will help toward a better understanding of geologic history and regional heat flow near the axis of active Cascade volcanism. The temperature-depth profile for the hole (Figure 7) is irregular with a high (120 °C/km) gradient in the lowermost part. Interpretation

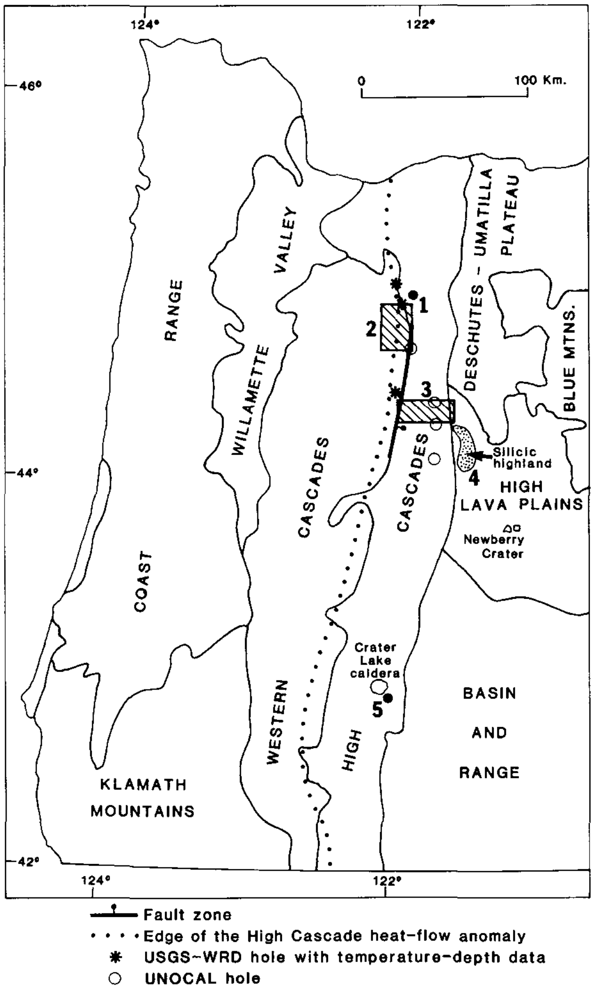


*Figure 5. Physiographic provinces of western Oregon (after Dicken, 1950), showing major areas of geothermal activity discussed in text. 1. Location of Thermal Power drill hole CTGH-1. 2. Breitenbush study area. 3. Santiam Pass study area. 4. Silicic highland study area. 5. Location of CEC drill hole MZI-11A. Edge of High Cascade heat-flow anomaly after Black and others (1983).*

of these data is still in an early stage, so no firm conclusions can be drawn.

George Priest and Brittain Hill of DOGAMI managed the project. Drilling engineering and contracting was conducted by W. Richard Benoit of OPC. OPC also retains ownership and regulatory responsibility for the drill hole. David D. Blackwell of Southern Methodist University conducted all geophysical logging of the hole and is analyzing the results, including determination of deep heat flow in the area (Figures 8 and 9).

Those interested in conducting scientific studies of the drill hole or samples are encouraged to contact this author for further information. The hole will be accessible for experiments in the early summer of 1991 but will be plugged and abandoned thereafter. Drill core and cuttings from the hole are stored at Oregon State University (OSU) in Corvallis. Contact Brittain E. Hill, Department of Geosciences, Oregon State University, Corvallis, OR 97331-5506 (phone 503-737-1201) for access to cores and cuttings.

Core from four temperature-gradient holes was donated to DOGAMI by UNOCAL in 1988 and is currently available for use in research projects. The holes, drilled in the central High Cascades (Figure 5, open circles), reached depths ranging from 250 to 610 m. No temperature data are publicly available from the holes, but detailed lithologic logs of the diamond core have been produced as part of DOGAMI's scientific drilling program.

## GEO-HEAT CENTER, OIT

The Geo-Heat Center at the Oregon Institute of Technology (OIT) in Klamath Falls specializes in assisting in the development of low-(<90 °C) and moderate-temperature (90°-150 °C) geothermal applications for direct use. The Center is under contract with USDOE to provide a limited amount (based on merit) of free technical and economic analysis services to private developers, engineering consultants, and public agencies throughout the U.S. The assistance can range from answering technical questions and simple consultation on methods, materials, equipment, and applications to troubleshooting problems in existing systems. The Center maintains a geothermal library of over 4,000 volumes, which is open to lay and technical readers; publishes a quarterly Bulletin with domestic and foreign authors and a "Geothermal Direct Use Engineering and Design Guidebook" of more than 400 pages; and is involved in applied research on direct applications.

The Center continues to be involved in the evaluation and monitoring of the Klamath Falls aquifer, and the staff plays an active role on the Klamath Falls Geothermal Advisory Committee.

## ACTIVITIES OF OREGON WATER RESOURCES DEPARTMENT

The Oregon Water Resources Department low-temperature geothermal program evaluated numerous proposals to inject spent geothermal effluent. This activity was largely the result of a City of Klamath Falls ordinance that now requires such injection within the city. Processing of these proposals is a coordinated effort with the Oregon Department of Environmental Quality and is required for a permit from that agency. By year's end, proposals from eighteen institutional, commercial, and domestic users were being processed in Klamath Falls. Injection rates under these proposals range from 2 to 450 gpm. In addition, an institution near Bend has submitted a proposal to inject 1,500 gpm.

WRD also regulates extraction of low-temperature (65°-256 °F) geothermal resources. Regulatory activities are summarized in the section on regulatory actions.

## ACTIVITIES OF OREGON DEPARTMENT OF ENERGY

In 1990, ODOE performed research on geothermal development issues for outside organizations and provided assistance to the public. Research included both ongoing joint research with the Washington State Energy Office (WSEO) and new work for the Bonneville Power Administration (BPA). Technical assistance includes tax credit reviews for public and agency clients.

In 1990, geothermal research with WSEO was limited to digital mapping of a representative prospect area (Mount Mazama). This work covered several 7½-minute topographic quadrangles and included transportation, topography, and well-location layers. This work was part of a regional effort to create renewable-energy site maps for the northwestern states. Only one site was digitized in 1990, but the goal is to expand the effort to include all renewable-energy sites in all northwestern states.

BPA initiated research to estimate local economic impacts of a 100-MW geothermal power plant project. These impact estimates are being done for hypothetical projects in Deschutes and Harney Counties, Oregon. Further research for BPA (to be completed in 1991) will include land use impact estimates and the assembling of a database of existing U.S. geothermal power plants.

The geothermal specialist of ODOE also participated in teaching a course on geothermal energy sponsored by Central Oregon Community College and, as a contribution to the annual Geothermal Resources Council meeting, published a paper on the Northwest market for geothermal power in the 1990's.

ODOE continues to certify geothermal tax credits for both homes and businesses in the state. The ODOE geothermal staff reviewed 80 residential tax credit applications in 1990. A total of 94 residential systems received final certification. The total number of geothermal residential tax credits issued from 1978 through 1990 is 690.

ODOE responds to inquiries on geothermal energy development from the public and answered 119 such inquiries in 1990. The agency has received an average of about 125 inquiries annually since 1984.

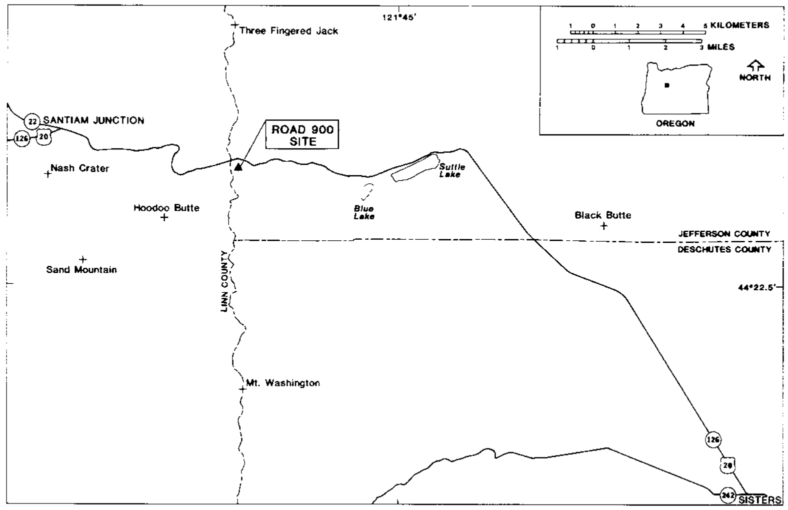


*Figure 6. Location of scientific drill site near Santiam Pass, Oregon.*

## RESEARCH BY OSU

Brittain E. Hill, a doctoral candidate at Oregon State University (OSU), is continuing his work on Quaternary ash flows in the Bend area (Hill, 1985) and the silicic highland west of Bend. He is also the field supervisor for scientific work on the scientific drill hole at Santiam Pass.

Jack Dymond and Robert Collier of the OSU College of Oceanography continued their investigation at Crater Lake National Park. Their objective is to determine whether or not geothermal input exists on the floor of the lake. Data collected in 1989 from a surface ship and a submarine were analyzed and summarized in a draft final report to the National Park Service. The report is still being reviewed but is expected to be finished in 1991.

## RESEARCH BY WASHINGTON STATE UNIVERSITY

Richard Conrey is finishing up a four-year doctoral study of the Mount Jefferson area. He found that, for the last 2.5 Ma, about 200 $km^2$ of the area has been the site of andesitic to rhyodacitic volcanism (Conrey, 1988). He postulates that a granodiorite-tonalite batholith lies at shallow depths beneath the area.

## MOUNT MAZAMA AREA (CRATER LAKE AREA)

The reader is referred to Black and Priest (1988) and Priest (1990) for a detailed history of geothermal development issues at Mount Mazama. No new exploration activity occurred in 1990.

The National Park Service is continuing the previously mentioned research by Jack Dymond and Robert Collier of OSU).

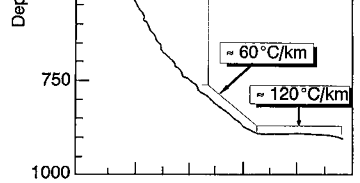


*Figure 7. Temperature-depth data from Santiam Pass drill hole 77-24, thirty days after the end of drilling. Note the rapid increase of temperature near the bottom.*

## ACKNOWLEDGMENTS

We acknowledge the cooperation of numerous individuals in government and industry. Jacki Clark of the U.S. Bureau of Land Management (BLM) provided the federal leasing data. Jack Feuer of BLM provided much useful information on regulatory issues. Dennis Olmstead and Dan Wermiel of DOGAMI furnished the data on drilling permits. George Darr of BPA, Alex Sifford of ODOE, and Donn Miller of WRD provided information on their agencies' activities for the year. Gene Culver of OIT provided information on OIT activities and the status of direct use projects around the state. David Sherrod of USGS supplied an account of USGS activities in Oregon. Jack Dymond of Oregon State University provided information on his study of Crater Lake.

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*Figure 8. Drill rig used for diamond coring at the Santiam Pass scientific drilling project. Rig was operated by the Tonto Drilling Company and is capable of drilling to 1.2 km. Drilling from 141 m to 928 m took 35 days starting August 14, 1990.*

*Figure 9. W. Richard (Dick) Benoit (left) of Oxbow Power Corporation, who conducted drilling engineering and contracting, and David D. Blackwell (right) of Southern Methodist University at the site of the Santiam Pass scientific drilling project.*


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# USGS completes 7½-minute quadrangle map series for Oregon

The culmination of a 42-year mapping effort in Oregon was celebrated on May 21, 1991, at the annual spring meeting of the State Map Advisory Council (SMAC) in Salem. A special ceremony attended by federal, state, and local government representatives marked the completion of first-time, 7½-minute topographic mapping for Oregon by the U.S. Geological Survey (USGS).

Roy Mullen, acting chief of the USGS National Mapping Division praised the State of Oregon for its cooperation in the project. He presented to Oregon Secretary of State Phil Keisling a commemorative certificate signed by U.S. Secretary of the Interior Manuel Lujan and prepared on a reproduction of the first Oregon topographic map published by the USGS, the 1893 map of the Ashland 1° by 1° quadrangle in Jackson County. He also presented a framed copy of the Drewsey quadrangle in Harney County, the final quadrangle map of the 7½-minute series.

In the now-complete series, Oregon's 96,981 square miles are covered on 1,944 separate map sheets at the scale of 1:24,000 (1 inch on the map equals about 2,000 feet on the ground). This is the most detailed map series published by the USGS. Each map covers 7½ minutes of latitude by 7½ minutes of longitude, which in Oregon represents an area of 52 to 55 square miles.

The ceremony at the meeting of SMAC also underlined the role of the Council in the mapping effort. SMAC is directed by executive order of the governor to coordinate and foster cooperative mapping efforts in Oregon. In 1979, under chairmanship of Deputy State Geologist John D. Beaulieu of the Oregon Department of Geology and Mineral Industries (DOGAMI), SMAC declared that statewide completion of the 7½-minute series was its top priority. With only 41 percent of the state completed in this series at that time, a plan was formulated to finish the entire state by the late 1980's. Elements of the plan included (1) a specific eight-year schedule with yearly monitoring of progress, (2) involvement of the Oregon congressional delegation to urge priority status for Oregon, (3) recruitment of a State Resident Cartographer to promote cooperative activities, and (4) adoption of a modified publication format—provisional maps, which are less refined graphically but more expeditiously completed.

The USGS began producing 7½-minute maps of Oregon in 1949 to replace the earlier 15-minute maps (scale 1:62,500) as the most detailed topographic maps. Other topographic map series by the USGS include the 1:100,000-scale and 1:250,000-scale series, state base maps at 1:500,000 and 1:1,000,000 scale, and national park maps. All these maps are available from the USGS and over the counter at DOGAMI offices.

The USGS effort will now focus on two further needs of the 7½-minute series. One is revising and updating the maps to keep pace with our rapidly changing landscape; the other is the conversion of these paper maps into digital (computer-stored) form to increase their utility. The USGS is building the National Digital Cartographic Data Base to provide a wide range of map data in computer-compatible form. As quadrangle map data are converted to digital form, production of new and custom maps and revision of these maps is greatly assisted. Furthermore, the availability of digital geographic data will enable wider use of geographic information systems to aid resource management, area analysis, and planning activities. *—Adapted from USGS news release*

# Cavansite and pentagonite from Lake Owyhee State Park, Malheur County, Oregon*

*by Jon Gladwell, 3235 SE 56th, Portland, Oregon 97206-2007, (503) 771-4123*

The two dimorphous calcium vanadium silicates cavansite and pentagonite are known to occur in a road cut at Lake Owyhee State Park , Malheur County, Oregon. State Park regulations prohibit mineral collecting on park land; however, the author; Mike Sunde; Alex, Karen, and Bonnie Huang; and Scott Sanderson were granted permission for limited collecting at the location during early 1990.

The locality is within the right-of-way of the Malheur County road that provides access to the state park and points south. Both the State and the County, in turn, lease the land from the U.S. Bureau of Reclamation. Therefore, it was necessary to secure approval from all three entities, and the Bureau of Reclamation coordinated the permit process. The result was a series of three collecting expeditions, which together yielded somewhat less than one thousand small specimens of cavansite and five specimens of pentagonite.

The deposit occurs in the south bank of the road cut, just northeast of the day-use area of the park. It is the last road cut before the road descends into the day-use area. Apparently, the deposit had not been heavily worked since road construction in the late 1950's, and so a considerable amount of weathered overburden and debris had to be removed before good material was exposed. The host rock, a palagonite tuff, is spongy in nature and is difficult to break cleanly. In most cases, hand-collecting techniques caused the matrix to peel apart into conchoidal sections resembling onionskin. As a result, most specimens show much matrix and only a little mineralization. From an aesthetic perspective, the most desirable specimens (and, of course, the least common) are the compact, tightly packed rosettes that we describe as "blueberries." Less tightly packed specimens, which tend to lie flatter, as well as those covered by secondary mineralization occur most frequently and are a much paler blue in comparison. In many cases, the cavansite is partially to completely covered with associated drusy heulandite, analcime, or calcite, which produces the paler color but adds sparkle.

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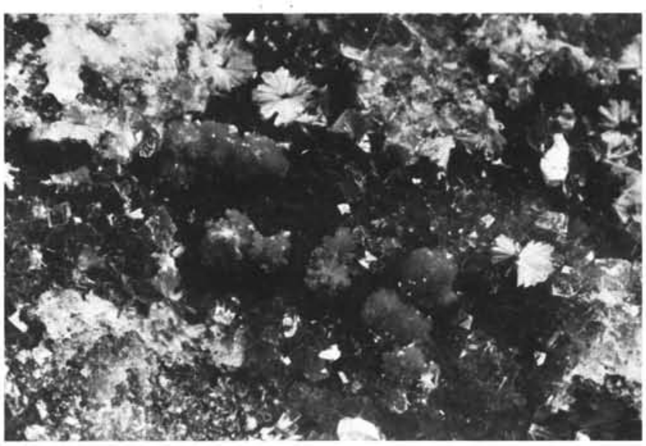
The pentagonite specimens were found in one small fracture that ran perpendicular to the main trend of the cavansite. Only five small pieces were recovered and were, in fact, identified only after the material had been brought home and examined closely.

The cavansite and pentagonite occur as sky-blue to greenish-blue, radiating prismatic rosettes up to 5 mm in diameter in isolated to packed groupings along small, narrow fractures in the palagonite lapilli tuff. The host rock is part of the Sucker Creek Formation (Corcoran, 1965), whose palagonite tuffs and breccias weather to form the brown and tan badland slopes on the east side of the park. Basalt and basaltic andesite flows of the Owyhee Basalt (Bryan, 1929) form the prominent, overlying, dark cliff faces. New geologic investigations of the Lake Owyhee region (Rytuba and others, 1990) indicate that both the palagonite tuffs and the overlying basalts were erupted and deposited in complex, fault-bounded basins developed during middle Miocene time. Many of the popular chalcedony, agate, and picture-rock deposits in the Lake Owyhee area were formed, along with calcite and calcite-zeolite vein systems, as the basins developed. Interestingly enough, many of these chalcedony and picture-rock occurrences are now under evaluation for hot-spring-type gold deposits.

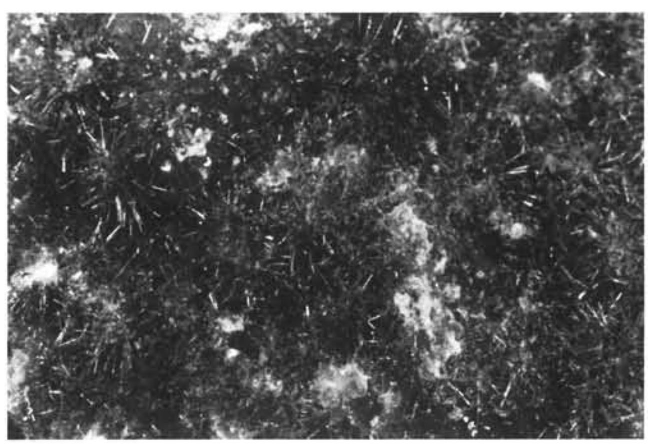
At this deposit, abundant colorless analcime, stilbite, chabazite, thomsonite, and heulandite, as well as colorless to pale-yellow calcite and rare green apophyllitye, are associated with the cavansite and pentagonite. The Lake Owyhee occurrence and a similar emplacement (of cavansite only) near Goble, Columbia County, Oregon (both co-type localities) are the only known deposits of these two minerals in the United States.

Minor localized faulting along the road cut has permitted the secondary mineralization in the interstitial spaces, which are typically less than 2 mm in width. In the hand specimens examined, it appears that the associated minerals were deposited contemporaneously with the cavansite and pentagonite. Many specimens occur with a portion of the cavansite covered by associates, while within a centimeter one will find a beautiful blueberry perched upon calcite or one of the zeolites.

The 1961 discovery of these two minerals at Lake Owyhee is attributed to Mr. and Mrs. Leslie Perrigo of Fruitland, Idaho. Later on, in 1963, Dr. John Cowles of Rainier, Oregon, discovered the Goble occurrence. Cavansite and pentagonite were first de-



*Cavansite, heulandite, and calcite from Owyhee State Park, Malheur County. Field of view is approximately 24 mm.*



*Pentagonite from Owyhee State Park, Malheur County. Field of view is approximately 24 mm.*

scribed in 1973 (Staples and others, 1973). These investigators used X-ray fluorescence and crystal-structure analysis to determine that cavansite ($Ca[VO]Si_4O_{10}\cdot 4H_2O$) is orthorhombic, conforms to space group Pcmn ($D_{2h}{}^{16}$), has a unit cell with a=10.298(4), b=13.999(7), and c=9.601(2) angstroms, contains four formula units, and is optically biaxially positive and strongly pleochroic. Pentagonite, the dimorph, occurs as prismatic crystals twinned to form fivelings with a star-shaped cross section. Also orthorhombic, it belongs to space group $Ccm2_1$ ($C_{2v}{}^{12}$) and has a unit cell with a=10.298(4), b=13.99(7), and c=8.891(2) angstroms, contains four formula units, and is biaxially negative. The cell dimensions given for these two species vary slightly, presumably because of varying zeolitic water content. Both cavansite and pentagonite have layer structures in which the individual layers are held together by $VO^{2+}$ groups and $Ca^{2+}$ ions, but they differ in the way the $SiO_4$ tetrahedra link to form the layers.

The collecting group intends to provide a representative specimen of cavansite free of charge to academic institutions (including primary and secondary schools) who may wish to add this species to their permanent collections. Interested educators should address requests to the author. Small specimens of cavansite will be provided upon request to interested collectors who inquire in person at Lake Owyhee State Park, but no mail inquiries will be honored. In addition, collectors who are unable to visit the park may obtain a small study specimen of cavansite by sending a check for $5.00, to cover packing and shipping costs, to the author at the address above. Additional specimens will not be available for purchase.

The collecting group gratefully acknowledges the efforts of the following individuals who worked together to arrange the permits and make the collecting trips possible: Jerold D. Gregg (Project Superintendent), James Brooks (Director of Lands), Brent Carter (District Geologist), Curtis Carney (Facility Manager), all from the Bureau of Reclamation, Central Snake Projects Office; Dan Rau (Park Ranger), State of Oregon; and Mark Ferns (District Geologist) and Jerry Gray (Economic Geologist), Oregon Department of Geology and Mineral Industries. The author also especially acknowledges the expert technical assistance of Mark Ferns. This effort stands as an example of successful cooperation between the private collecting fraternity and the local, state, and federal regulatory agencies.

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Staples L.W., Evans, H.T., Jr., and Lindsay, J.R., 1973, Cavansite and pentagonite, new dimorphous calcium vanadium silicate minerals from Oregon: American Mineralogist, v. 58, p. 405-411. □

# Cascade Range volcanoes are just dormant

*(This brief introduction to the volcanism of the southern Cascade Range is an adaptation of a recent release from the Grants Pass field office of the Oregon Department of Geology and Mineral Industries.)*

The year 1990 marked the 10th anniversary of the eruption of Mount St. Helens (1980) and the 75th anniversary of the eruption of Mount Lassen (1915). We also know of relatively "recent" eruptions of other dormant Cascade Range volcanoes: Mount Hood in 1865, 1859, and the late 1700's; Mount Shasta in 1786; the Three Sisters area in A.D. 800, A.D. 400, and 0-300 B.C.; Newberry Volcano in A.D. 700; and the Crater Lake volcanic complex (Mount Mazama) in 2000 B.C. and 5600 B.C. Eruptions of Mount McLoughlin in southern Oregon have dates between one million years and ten thousand years, but several undated lava flows on the mountain are suspected by scientists to be younger than that. The history written by these and thousands of other eruptions is the history of the formation of the Cascade Range.

Volcanoes in the Cascade Range occur in a band that parallels the Pacific Coast. This orientation is not accidental: it is related to the boundary between the Pacific Ocean and the North American continent, the line where two moving pieces of the Earth's crust meet. Low-density continental crust that forms North America is creeping westward (about as fast as a fingernail grows) and riding over dense oceanic crust that forms the floor of the Pacific Ocean. The oceanic crust is heated as it sinks deep beneath the continent and eventually melts. The resulting lava rises to the surface at Cascade Range volcanoes. Volcanoes are not found in the Coast Range because the oceanic crust below is not yet deep enough or hot enough to cause melting of the rock.

Geologists of the U.S. Geological Survey (USGS) estimate that over the past 730,000 years the Cascade Range in southern Oregon alone (south of Eugene) has erupted an average of 1.3 million cubic yards of lava (enough to bury an area of 100 acres under an 8-foot-thick layer of lava)—per year. This estimate is conservative: it does not, for instance, consider that some lavas are erupted and deposited in the form of low-density pumice, which can mean a five-fold expansion in volume. The estimate is also an average amount, which means that in individual eruptions volcanoes tend to produce much larger amounts of lava in comparatively short periods that may be separated by tens, hundreds, or thousands of quiet years. Mount St. Helens discharged about 500 times the average amount in just a few minutes during the 1980 eruption.

When an eruption occurs, the hazards accompanying it vary with the type of eruption, the drainage patterns of the area, and the prevailing wind. Volcanic flows, landslides, avalanches, and high-density gases may follow stream valleys and gullies for miles, leaving them only when propelled by their own momentum. Volcanic ash from explosive eruptions is blown downwind. With winds blowing predominantly to the east or southeast, the eruptions of Mount Mazama (Crater Lake) and Mount St. Helens both produced thick ash deposits in those directions. Flooding is another major concern during eruptions. Floods occur when runoff from rapidly melting snowpack and glaciers breaches unstable temporary dams created by mudflows, logjams, landslides, or avalanches.

For an estimate of the frequency of eruptions and, on that basis, projections for future eruptions, Mount Shasta is probably better studied than any other volcano in the area. USGS volcanologists report that Shasta has erupted 10 or 11 times in the last 3,400 years and at least three times in the last 750 years and that the last eruption was in 1786. Assuming that the volcano's behavior has not changed, they give, for any given decade, odds of one in 25 to one in 30 that Mount Shasta will erupt again.

Geologists learned a great deal about the behavior of Cascade Range volcanoes by monitoring Mount St. Helens. Scientists hope that the relationship they observed between lava movement, vent activity, shallow earthquakes, and eruptions at Mount St. Helens will be representative of Cascade Range volcanism in general and that eruptions of other volcanoes in the Cascades can be predicted in a similar manner. □

# Welded tuffs of the Winberry Creek area, central Oregon Cascade Range

*by Gary L. Millhollen, Department of Earth Sciences, Fort Hays State University, Hays, Kansas 67601*

## INTRODUCTION

Densely welded tuffs are present in the North Fork Winberry Creek drainage east of Fall Creek Reservoir in Lane County, Oregon (Figure 1). Western Cascade volcanic rocks are dominantly volcaniclastic in this area, although some lavas also are present (Millhollen, 1989).

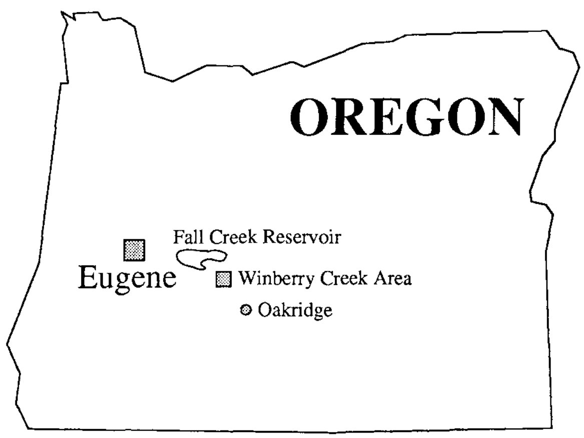


*Figure 1. Sketch map showing location of Winberry Creek area.*

The welded tuffs described here occur in road cuts along the North Fork of Winberry Creek (samples 1 and 2, Table 1) and on the slopes of Winberry Mountain (samples 3-5, Table 1). The first two analyzed samples are from the same road cut in a black, glassy zone that is about 4 m thick (see explanation, Table 1). Ash-flow zoning patterns (Smith, 1960) are difficult to determine in these exposures because of alteration in the more porous rocks, but less densely welded zones, including zones with devitrified glass shards, are also apparent in the road cuts of the first three samples in Table 1. Sherrod and Smith (1989) described widespread alteration of glass and other unstable materials in pyroclastic-flow deposits older than 10 Ma (million years before the present) in the Oregon Cascade Range as being very low-grade metamorphic recrystallization. Because the densely welded tuffs show little alteration or metamorphism, this process must be controlled by access of water in more permeable rocks.

The ash flows that produced these welded tuffs probably were of relatively small volume, given the limited extent of the densely welded zones in existing exposures. If they were of small volume, they probably were erupted from vents relatively near these exposures because of the requirement of sufficient heat for dense welding.

The five analyzed samples resemble black obsidian in hand specimen, but in thin section (Figure 2) they show distinctive eutaxitic texture characterized by flattened and deformed glass shards, as described by Ross and Smith (1961). The glass is pale brown to colorless and is mostly isotropic. All five samples contain abundant plagioclase phenocrysts, opaque grains (Fe-Ti oxides), and minor lithic fragments, but the nature of the pyroxene phenocrysts in sample 3 (Table 1) is different from that in the other samples. Sample 3 contains similar amounts of clinopyroxene and orthopyroxene, whereas the other four samples contain dominantly clinopyroxene plus a partly altered mineral that probably is a ferroan orthopyroxene (ferrosilite, according to the nomenclature of Morimoto, 1988). Clinopyroxene grains in all samples are pale-green augite. Peck and others (1964) described the pyroxenes in the welded tuff at the locality of the first two samples here as being ferroaugite (now Fe-rich augite) and less abundant eulite (now ferrosilite).

Table 1. *Chemical analyses and CIPW norms of welded tuffs*

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 |
|---|---|---|---|---|---|
| | **Major elements (weight percent)** | | | | |
| $SiO_2$ | 67.70 | 67.85 | 68.27 | 69.01 | 69.01 |
| $TiO_2$ | 1.79 | 1.52 | 0.65 | 0.37 | 0.29 |
| $Al_2O_3$ | 13.45 | 13.36 | 13.24 | 13.44 | 13.10 |
| $Fe_2O_3$ | 0.69 | 1.23 | 0.15 | 0.35 | 0.85 |
| FeO | 3.27 | 2.58 | 3.75 | 3.57 | 2.70 |
| MnO | 0.13 | 0.13 | 0.12 | 0.15 | 0.12 |
| MgO | 0.19 | 0.14 | 0.82 | 0.22 | 0.14 |
| CaO | 1.93 | 1.63 | 1.75 | 1.94 | 1.72 |
| $Na_2O$ | 5.02 | 4.32 | 3.57 | 4.00 | 4.00 |
| $K_2O$ | 2.23 | 2.64 | 2.58 | 3.07 | 3.64 |
| $P_2O_5$ | 0.04 | 0.04 | 0.16 | 0.04 | 0.04 |
| $H_2O^+$ | 3.09 | 3.21 | 3.03 | 3.93 | 3.51 |
| $H_2O^-$ | 0.89 | 1.02 | 1.61 | 0.67 | 0.56 |
| Total | 100.42 | 99.67 | 99.70 | 100.79 | 99.68 |
| | **Trace elements (ppm)** | | | | |
| Li | 5.5 | 7.4 | 9.2 | 11 | 12 |
| Cr | 346 | 111 | 327 | 126 | 158 |
| Ni | 15 | 6.5 | 18 | 11 | 11 |
| Cu | 334 | 165 | 236 | 144 | 208 |
| Zn | 220 | 161 | 174 | 157 | 176 |
| Rb | 71 | 82 | 50 | 69 | 77 |
| Sr | 154 | 120 | 177 | 156 | 119 |
| Ba | 725 | 665 | 740 | 700 | 740 |
| | **CIPW norms (weight percent)** | | | | |
| Q | 25.71 | 29.72 | 32.00 | 28.00 | 27.69 |
| Or | 13.66 | 16.35 | 16.04 | 18.87 | 22.50 |
| Ab | 44.05 | 38.30 | 31.78 | 35.20 | 35.40 |
| An | 7.86 | 8.20 | 8.03 | 9.74 | 7.36 |
| Di | 1.56 | — | — | — | 1.13 |
| Hy | 2.50 | 1.89 | 8.37 | 6.74 | 3.95 |
| Mt | 1.04 | 1.87 | 0.23 | 0.53 | 1.29 |
| Il | 3.52 | 3.02 | 1.30 | 0.73 | 0.58 |
| Ap | 0.10 | 0.10 | 0.40 | 0.10 | 0.10 |
| C | — | 0.55 | 1.87 | 0.11 | — |

**Explanation:** Co <5 ppm in all samples. All are black, vitrophyric, densely welded tuffs.

Sample 1. From upper middle part of black vitrophyre in road cut on Forest Service Road 1802 along North Fork Winberry Creek; same location as analysis 15 of Peck and others (1964), p. 45; middle part of sec. 20, T. 19 S., R. 2 E.; sample 80M019.

Sample 2. From about 10 cm below the top of the black vitrophyre; same location as 1 above; sample 80M020.

Sample 3. From road cut on Forest Service Road 188 (Lowell Ranger District map); NW¼ sec. 28, T. 19 S., R. 2 E.; sample 80M096.

Sample 4. From road cut on Forest Service Road 188; NE¼ sec. 28, T. 19 S., R. 2 E.; sample 81M094.

Sample 5. From large boulder on track of Forest Service Road 188; near west-central edge of sec. 27, T. 19 S., R. 2 E.; sample 81M106.

Analyses by Christine McBirney, AA Laboratory, Department of Geological Sciences, University of Oregon, Eugene.

*Figure 2. Photomicrograph of densely welded tuff along the North Fork Winberry Creek (sample 1, Table 1, plane-polarized light. Eutaxitic texture is defined by flattened and deformed glass shards. Two clinopyroxene grains are near center of photo; the one containing opaque grains is about 0.3 mm in long dimension. Three large plagioclase grains are near edges of photo.*

## AGE RELATIONS

The age of the first sample in Table 1 was determined by whole-rock K-Ar methods to be 21.6 Ma (Millhollen, 1989). This corresponds to the early Western Cascade volcanic episode of Priest and others (1983) or to Oregon Cascade Range time unit $T_3$ of Sherrod and Smith (1989).

Relative age relations are difficult to determine in this area because of (1) limited rock exposures due to thick soils and dense vegetation and (2) the effects of eruption onto an existing topography that was probably irregular, with flows tending to follow topographic lows. The three welded tuff samples for which ages are not available (samples 3-5, Table 1) are from somewhat higher elevations across North Fork Winberry Creek from the dated welded tuff (samples 1 and 2, Table 1), implying somewhat younger ages. However, although dips are very gentle and variable in this area, a dip of about 8° could account for the difference in elevation. Because of petrographic similarities and close association in the field and because of chemical similarities described below, samples 4 and 5 (Table 1) are believed to be from the same welded ash flow, whereas sample 3 is probably from a different ash flow.

A dacite from a quarry along South Fork Winberry Creek at an elevation roughly midway between those of the dated welded tuff and the other welded tuffs has an age of 16.6 Ma (Millhollen, 1989). This age corresponds to the early part of the late Western Cascade volcanic episode of Priest and others (1983) or of time unit $T_2$ of Sherrod and Smith (1989). Because of the uncertainties in relative age relations, the two apparently younger ash flows should be regarded as being of either late early Western Cascade or early late Western Cascade age.

## CHEMICAL COMPOSITIONS AND MAGMA EVOLUTION

All five of the analyzed samples are densely welded, vitrophyric tuffs of rhyolitic composition, according to the IUGS chemical classification scheme (Le Maitre, 1984). Some chemical differences among the analyses (Table 1) are believed to reflect the fact that the five samples are from three different ash flows. For example, $TiO_2$ contents are highest in samples 1 and 2, intermediate in 3, and low in 4 and 5; these differences are also apparent when the analyses are normalized to 100 percent volatile-free.

All samples are hydrated (Table 1), but they are not oxidized, and they show only incipient alteration or metamorphism in thin section. The percentages of $TiO_2$ and other elements that are essentially immobile during hydration might change if other constituents are added to or subtracted from the rock, but the ratio of two immobile elements would be unaffected by the hydration process. Of the major elements, $TiO_2$ and $Al_2O_3$ are most likely to be immobile, so that any differences in $Al_2O_3/TiO_2$ ratios should reflect magmatic compositional differences. Since all five samples have similar $Al_2O_3$ contents (Table 1 and normalized "dry" values), the different $TiO_2$ contents are reflected in different $Al_2O_3/TiO_2$ ratios (Figure 3), with samples 1 and 2 having low ratios, 3 intermediate, and 4 and 5 high ratios. Like $Al_2O_3$, $SiO_2$ contents are similar for all five samples (Table 1 and normalized values), so $SiO_2/Al_2O_3$ ratios are similar for all samples (Figure 3). However, some $SiO_2$ may be lost during hydration of glass (several studies summarized by Fisher and Schmincke, 1984).

Figure 4 shows some other chemical differences to support the hypothesis that the samples are from three different ash flows. Samples 1 and 2 and samples 4 and 5 plot as separate pairs, while sample 3 plots away from the others. Since K and Rb show similar magmatic geochemical behavior, the K/Rb ratio should reflect the parent magma and source rock compositions plus any effects of assimilation or magma mixing; fractionation of plagioclase should have had little effect on this ratio. The Ti/Rb ratio, however, is a ratio of a high field strength (HFS) element to a low field strength, or large ion lithophile (LIL), element. This ratio may also reflect differences in parent magma and source rock compositions, as well as assimilation and magma mixing, but it may also be affected significantly by fractionation of clinopyroxene and especially Fe-Ti oxide. A possible weakness of this plot is that K and Rb contents may change during hydration of glass, although Zielinski and others (1977) found no significant change in Rb contents due to hydration of rhyolitic glasses.

The CIPW norm (Table 1) shows that sample 3 is distinctly peraluminous (normative corundum). Comparison of the norms of samples 1 and 2 indicates that this welded tuff probably is metaluminous (normative diopside in 1 exceeds normative corundum in 2). Similarly, the welded tuff of samples 4 and 5 also

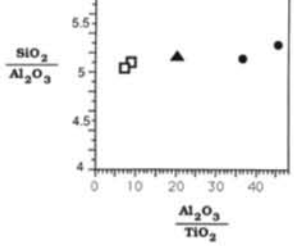


*Figure 3. Major-element ratios of $SiO_2/Al_2O_3$ - $Al_2O_3/TiO_2$. Open boxes are samples 1 and 2, filled triangle is sample 3, filled circles are samples 4 and 5 of Table 1.*

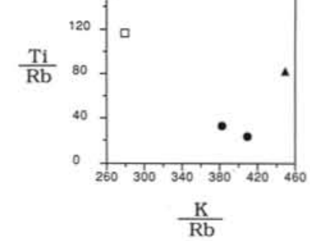


*Figure 4. Ppm ratios of Ti/Rb - K/Rb. Open boxes are samples 1 and 2, filled triangle is sample 3, and filled circles are samples 4 and 5 of Table 1.*

probably is metaluminous. However, norms also may be affected by chemical changes during hydration.

Since the welded tuffs contain minor lithic fragments, these might contribute somewhat to chemical differences observed. Also, eruption from a chemically zoned magma chamber can produce chemical variation in a single ignimbrite (e.g., Hildreth, 1981). The ash flows of the welded tuffs studied here probably were of too small a volume to show chemical variation. However, the petrographic similarity among samples 1, 2, 4, and 5 suggests the possibility that these welded tuffs may be from the same ash flow, with sample 3 being from a second ash flow.

Although existing data are inadequate for accurate modeling of the evolution of these magmas, simple major-element mass-balance mixing calculations were used to test the hypothesis that these silicic magmas may have been derived from more mafic magmas mainly by fractional crystallization of clinopyroxene, orthopyroxene, plagioclase, and Fe-Ti oxide, phases that are present in the welded tuffs and in lavas in this area (Millhollen, 1989). Initial calculations used compositions of these lavas (from Millhollen, 1989) and compositions of the above mineral types from island arc gabbros in Alaska (DeBari and Coleman, 1989). The gabbroic minerals were chosen to represent arc magma chamber minerals. Sübsequent calculations added ideal quartz ($SiO_2$) and K-feldspar ($KAlSi_3O_8$) to include possible effects of assimilation of these minerals.

Table 2 shows the results of calculations using an early Western Cascade basaltic andesite from the Winberry Creek area (53.5 percent $SiO_2$ normalized volatile-free; number 2 in Table 1 of Millhollen, 1989) as the parent magma composition for all calculations. The calculations used the least-squares method to minimize the sum of the squares of the residuals (R-sq in Table 2). Values of R-sq less that 1 are considered reasonable and less than 0.3 a good fit. For each sample calculation as presented in Table 2, the sum of fractionated minerals minus the sum of assimilated minerals equals 100 percent.

Because of the simple approach used, too much emphasis should not be placed on the numbers shown in Table 2. However, the results are consistent with the hypothesis that fractional crystallization was the dominant process of magma evolution, with assimilation playing a lesser and variable role. Plagioclase is the dominant fractionating mineral, which is consistent with its abundance as a phenocryst mineral in rocks in this area. Pyroxenes, especially clinopyroxene, are also important fractionating minerals in these calculations. The presence of plagioclase and pyroxene phenocrysts in the rocks and the absence of hornblende and biotite suggest that fractionation occurred in shallow crustal magma chambers.

Possible sources of error in these calculations include inappropriate mineral compositions, especially due to changing solid-solution compositions during magma evolution, and the effects of magma mixing. But since these rocks are silicic, magma mixing probably was not a major process, at least in the later stages of evolution that produced rhyolitic magmas. Basaltic rocks of the early Western Cascades in this area also contain altered groundmass (Millhollen, 1989), which is another possible source of error for calculations using compositions of these rocks as parent magmas. The immediate parent magma probably was of intermediate composition and may have evolved by a combination of processes, such as the MASH hypothesis of Hildreth and Moorbath (1988).

Table 2. *Results of mass-balance calculations*

| Sample | Plag | Cpx | Opx | Mt | Il | Qtz | Kf | R-sq |
|---|---|---|---|---|---|---|---|---|
| 1 | 68.7 | 17.7 | 13.8 | 3.8 | 1.5 | -4.7 | -0.8 | 0.92 |
| 2 | 71.9 | 20.6 | 14.1 | 4.0 | 1.5 | -8.8 | -3.4 | 0.62 |
| 3 | 78.7 | 26.8 | 12.6 | 4.3 | 2.7 | -18.2 | -6.8 | 0.20 |
| 4 | 75.0 | 21.2 | 15.1 | 3.3 | 2.9 | -11.5 | -6.0 | 0.50 |
| 5 | 75.5 | 19.7 | 15.4 | 3.4 | 2.9 | -9.7 | -7.3 | 0.56 |

Explanations: Sample numbers are the same as in Table 1. Positive values indicate fractionation; negative values indicate assimilation. Values are expressed as percentages. Plag=plagioclase, Cpx=clinopyroxene, Opx=orthopyroxene, Mt=magnetite, Il=ilmenite, Qtz=quartz, Kf=K-feldspar, R-sq=sum of the squares of the residuals. See text for further explanation.

## CONCLUSIONS

Three ash flows that were erupted in the vicinity of what is now Winberry Mountain and North Fork Winberry Creek during the later part of the early Western Cascade volcanic episode of Priest and others (1983)—and possibly during the early part of the late Western Cascade episode—formed densely welded, vitrophyric zones. The rhyolitic magmas that produced these ash flows probably evolved from more mafic magmas mainly by fractional crystallization of plagioclase, clinopyroxene, orthopyroxene, and Fe-Ti oxide in shallow crustal magma chambers. Assimilation of crustal materials also contributed to magma evolution. Magma mixing may have affected magma compositions in early stages but probably was not important in later stages of magma evolution.

## ACKNOWLEDGMENTS

I would like to thank Paul Hammond for his comments on densely welded tuffs, David Sherrod for a copy of his open-file report, and George Priest for his suggestions on improving the manuscript. The program GPP by D.J. Geist, B.H. Baker, and A.R. McBirney was used for the mass-balance calculations. This work has been supported in part by research grants from the Fort Hays State University Graduate School.

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# MINERAL EXPLORATION ACTIVITY

## MAJOR MINERAL-EXPLORATION ACTIVITY

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Baker 1991* | Cave Creek Nerco Exploration | T. 11, 12 S. R. 42 E. | Gold | App |
| Baker 1991 | Gold Ridge Mine Golconda Resources | T. 12 S. R. 43 E. | Gold | Expl |
| Baker 1992* | Pole Creek Placer Dome U.S. | T. 13 S. R. 36 E. | Gold, silver | Expl |
| Crook 1988 | Bear Creek Freeport McMoRan | Tps. 18, 19 S. R. 18 E. | Gold | Expl |
| Crook 1991 | Bear Creek Project Coeur Explorations | T. 18 S. R. 18 E. | Gold | Expl |
| Grant 1990 | Prairie Diggings Western Gold Explor. | T. 13 S. R. 32 E. | Gold | Veg |
| Grant 1992* | Standard Mine Bear Paw Mining | T. 12 S. R. 33 E. | Gold, copper | Expl |
| Harney 1990 | Pine Creek Battle Mtn. Explor. | T. 20 S. R. 34 E. | Gold | Expl |
| Jefferson 1991 | Red Jacket Bond Gold | Tps. 9, 10 S. R. 17 E. | Gold | App |
| Josephine 1990 | Martha Property Cambiex USA, Inc. | T. 33 S. R. 5 W. | Gold | Expl |
| Lake 1988 | Quartz Mountain Wavecrest Resources. | T. 37 S. R. 16 E. | Gold | Expl |
| Lake 1990 | Glass Butte Galactic Services | Tps. 23, 24 S. R. 23 E. | Gold | Expl |
| Lane 1990 | Grouse Mtn. Project Bond Gold Exploration | T. 23 S. Rs. 1, 2 E. | Gold | Expl |
| Lincoln 1991* | Iron Mtn. Quarry Oreg. St. Highw. Div. | T. 10 S. R. 11 W. | Basalt | App |
| Malheur 1988 | Grassy Mountain Atlas Precious Metals | T. 22 S. R. 44 E. | Gold | Expl, com |
| Malheur 1988 | Harper Basin Project Amer. Copper & Nickel | T. 21 S. R. 42 E. | Gold | Expl |
| Malheur 1988 | Jessie Page Chevron Resources Co. | T. 25 S. R. 43 E. | Gold | Expl |
| Malheur 1988 | Kerby Malheur Mining | T. 15 S. R. 45 E. | Gold | Expl, com |
| Malheur 1989 | Hope Butte Chevron Resources Co. | T. 17 S. R. 43 E. | Gold | Expl, com |
| Malheur 1990 | Ali/Alk Atlas Precious Metals | T. 17 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Buck Gulch Teague Mineral Prod. | T. 23 S. R. 46 E. | Ben-tonite | Expl |
| Malheur 1990 | Calavera NERCO Exploration | T. 21 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Cow Valley Butte Cambiex USA, Inc. | T. 14 S. R. 40 E. | Gold | Expl |
| Malheur 1990 | Freezeout Western Mining Corp. | T. 23 S. R. 42 E. | Gold | Expl |
| Malheur 1990 | Goldfinger Site Noranda Exploration | T. 25 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Grassy Mtn. Regional Atlas Precious Metals | T. 22 S. R. 44 E. | Gold | Expl |
| Malheur 1990 | Katey Claims Asarco, Inc. | Tps. 24, 25 S. Rs. 44, 46 E. | Gold | Expl |
| Malheur 1990 | KRB Placer Dome U.S. | T. 25 S. R. 43 E. | Gold | App |



| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Malheur 1990 | Lava Project Battle Mtn. Explor. | T. 29 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Mahogany Project Chevron Resources | T. 26 S. R. 46 E. | Gold | App |
| Malheur 1990 | Racey Project Billiton Minerals USA | T. 13 S. R. 41 E. | Gold | Expl |
| Malheur 1990 | Sand Hollow Noranda Exploration | T. 24 S. R. 43 E. | Gold | Expl |
| Malheur 1990 | Stockade Mountain BHP-Utah Intl. | T. 26 S. Rs. 38, 39 E. | Gold | Expl |
| Malheur 1990 | Stockade Project Phelps Dodge Mining | Tps. 25, 26 S. R. 38 E. | Gold | Expl |
| Malheur 1991* | Lucky G Sunshine Prec. Metals | T. 22 S. R. 44 E. | Gold | App |
| Malheur 1991 | Rhinehardt Site Atlas Precious Metals | Tps. 18, 19 S. R. 45 E. | Gold | Expl |
| Malheur 1991* | Sagebrush Gulch Kennecott Exploration | Tps. 21, 22 S. R. 44 | Gold | App |
| Malheur 1991* | Silver Claims Sunshine Prec. Metals | T. 23 S. R. 43 E. | Gold | App |
| Malheur 1991 | White Mountain D.E. White Mtn. Mining | T. 18 S. R. 41 E. | Dia-toms | App |
| Malheur 1991* | Big Red Ron Johnson | T. 20 S. R. 44 E. | Gold | Expl |
| Marion 1990 | Bornite Project Plexus Resources | T. 8 S. R. 3 E. | Copper | App com |

Explanations: App=application being processed. Expl=Exploration permit issued. Veg=Vegetation permit. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. *=New site

### Status changes

The number of permits issued continued to grow during the first year of the exploration-permit requirements program.

The new category of "Veg" is now shown in the status column for sites where all earth moving and seeding have been done, but the permit will not be released until revegetation is successful. During this final period of a permit, the fee and bond are reduced.

The application from Atlas Precious Metals for a permit to take a bulk sample from their Grassy Mountain project was determined to be incomplete. A revised application is expected.

A project-coordinating committee has been set up for the Bornite Project of Plexus Resources Corporation in Marion County.

### Regulatory issues

Numerous bills relating to mining have been introduced into the legislative session. House Bill 2244, significantly modified by the Governor's Mine Work Group, a multi-interest-based committee, was passed by House and Senate in slightly differing versions. At press time, all amendments had been agreed to by the conference committee.

Hearings have been held by the Department of Environmental Quality on its proposed water quality regulations for large-scale mining operations. Comments made during the hearings will be reviewed before the rules are presented to the Environmental Quality commission for adoption.

Questions or comments should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office, 1534 Queen Avenue SE, Albany, OR 97321, telephone (503) 967-2039. □

# MLR honors mining operators

In May, the Mined Land Reclamation (MLR) program of the Oregon Department of Geology and Mineral Industries presented several awards to mining operators for their exemplary efforts in conducting environmentally beneficial mining operations and reclamation programs.

**Outstanding Operator Award**

Awards for outstanding operator were given to Morse Brothers, Inc., for its Progress Quarry near Beaverton and to Bonnanza Mining, Inc., for its operation near Halfway. In both cases, the operators exceeded the requirements of their permits to provide excellent environmental protection in the day-to-day operation of the facilities.

Three other operators received an honorable mention: Howard DeYoung at Talent, Eagle Picher Mineral Industries at Vale, and S2F Corporation at Philomath.

**Reclamation Award**

The Reclamation Award went to LTM for its Kendall Bar project. Given to the operator whose completed reclamation exemplifies best the goals of the reclamation statutes of the State of Oregon, the award recognizes LTM's reclamation efforts for including raptor nest sites, islands, irregular shorelines, and fish structures (to enhance fish habitat), which added to the cost of the project but achieved a type of reclamation that blends exceptionally well with surrounding land use.

*Bonnanza Mining, Inc., operation near Halfway, Baker County, showing the mining cut before backfilling. View is to the north, upstream along the Pine Creek channel hidden in the trees.*

*The same Bonnanza Mining operation area as in photo above, after completion of backfilling. View is to the south. Ponded area in background is a newly created artificial wetland area.*

*Morse Brothers, Inc., Progress Quarry operation near Beaverton, Washington County. Mined-out quarry area is being backfilled with about 600,000 yds of clean material for protection of ground water.*

Honorable mention was awarded to O'Neill Sand and Gravel near Redmond for the O'Neill Junction site and to Beaver State Sand and Gravel of Roseburg for its Brosi pit.

**Exploration Reclamation Award**

This award, given to the exploration permittee whose completed reclamation exemplifies the goals of the reclamation requirement of the State, was given to Malheur Mining, Inc., for the reclamation accomplished at the company's Kerby project.

Horizon Gold Shares, Inc., received honorable mention for its reclamation at the Hope Butte exploration site.

**Agency Reclamation Award**

MLR also honors government agencies whose reclamation efforts exceed State of Oregon reclamation requirements. This year, the recognition was awarded to the Region 4 Office of the Oregon State Highway Division for reclaiming, during the award time period, six sites of which two were exempt from the reclamation requirement.

The Tualatin Fire District and Umatilla County received honorable mention in this category.

**Good Neighbor Award**

MLR's Good Neighbor Award for outstanding community service was given to Howard DeYoung of Talent for the exemplary community spirit he demonstrated. Besides completing excellent reclamation work at the company's Bear Creek site, Mr. DeYoung volunteered equipment and time to the community to accomplish reclamation tasks unrelated to his mining operation.

**Small Miner Award**

Two awards were given: The first went to Fred Smith and Sons of Brownsville, Linn County, who have been mining aggregate and completing concurrent reclamation since the early 1970's, creating fish and wildlife habitat in the mined areas without any obligation through bonding or formal reclamation requirements. The second award was given to the Eastern Oregon Mining Association, honoring seven of its members, Butch Bullard, John Lyons, George Spears, Lyle Chadwick, Max Buckner, Erv Lamb, and Tiny Malone, who, besides being independent operators, contributed their volunteer efforts in reclaiming a number of mining sites that had been abandoned by others. □

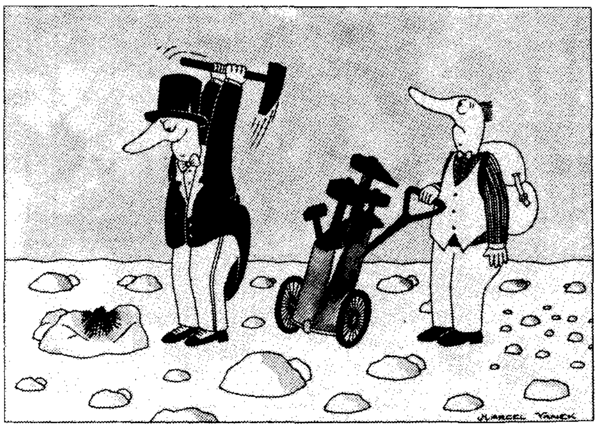
# BOOK REVIEWS

**Crystal Quest 1**, by Marcel Vanek. Published 1991 by Geoscience Press, Inc., 1040 Hyland Circle, Prescott, AZ 86303. Four pages of introductory text by the artist, 89 pages of cartoons, $9.95.

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

This little volume (8½ by 5½ inches) contains 76 one- or two-page cartoons, half of them in color. In his introduction, the artist describes the mineral collector's unflagging quest for true paradise. He illustrates it by showing how in the Garden of Eden the serpent offers to Adam and Eve—not the apple from the Tree of Knowledge but rock hammers.

The cover blurb states: "It is said that Marcel Vanek picked up his first rocks as a baby in Bratislava, Czechoslovakia, in 1964. Today, his vast mineral collection includes many fine specimens from classic Czechoslovakian localities—and three fossils. If you care to count, he claims to have painted 673 mineral species into his 199 mineralogical cartoons."



*From* Crystal Quest 1. *Used with permission of the publisher, Geoscience Press, Inc., Prescott, AZ. Copyright 1991 by Marcel Vanek.*

Vanek may have started out as a mineralogist, but now he is a cartoonist. His cartoons are in a typical central European style, consisting mostly of wordless, highly sardonic (no pun intended!), biting, and sometimes risqué comments on the human foibles of mineral collectors and fantastic encounters with the objects of their quest. Actually, Vanek reminds me more of Gary Larson than of any other U.S. cartoonist.

The cartoons were originally published in 1990 in Germany under a spoofy title that might be rendered as *Journal of Caricatural Mineralogy, Volume 1, Number 1.* The few words, mostly names, in the cartoons were left untranslated by the U.S. publisher, since they are easily understood—including even such exotic mineral names as "sexite"!

I am sure that some rock and mineral collectors will cringe when looking at some of Vanek's caustic visual comments. I am also sure that others will get many a chuckle. Some examples:

Dedication: Collector (hammer sticks out of his backpack) who is obviously agitated and concerned comes running to the end of the pier where a determined suicide candidate is just jumping off, carrying a large rock that is tied to his neck. That is panel one. In panel two, the collector is back on the pier, dripping wet but happily applying his hammer to the rock that still has the suicide candidate's rope tied around it. The cut-off end of the rope and the bubbles on the water next to the pier leave no doubt that here is a really dedicated collector!

Risks of the trade: Two collectors carrying G-picks like pistols in their belt holsters are facing each other, ready to "draw" for a high-noon "shootout" over possession of the giant amethyst geode that lies between them.

Nightmares: Collector in a cave breaks off a dripping stalactite (panel one), only to get washed out of the cave (panel two) by the torrent of water gushing out of the—hollow!—stalactite remnant in the cave ceiling.

Pleasant dreams: Metallic meteorites have a special "attraction" for this collector's clever, labor-saving device: He does not search for them or race after them as they fall (like some of his colleagues in the book)—he just stands by with a smile on his face while his giant horseshoe magnet catches one meteorite after the other.

But I should give away no more of these! You should get a copy and see for yourself.

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**Paleozoic and Early Mesozoic Paleogeographic Relations: Sierra Nevada, Klamath Mountains, and Related Terranes**, ed. by D.S. Harwood and M.M. Miller. Published 1990 by Geological Society of America, Boulder, Colorado, as Special Paper 255, 422 p., softbound, $62.

*Reviewed by Tom Wiley, Regional Geologist, Grants Pass Field Office, Oregon Department of Geology and Mineral Industries*

The editors Harwood and Miller have collected 25 papers that emphasize Paleozoic and early Mesozoic terranes in northern California and their ties to the western margin of cratonal North America. The book is divided into five sections: (1) Early and middle Paleozoic magmatic-arc, basinal, and ophiolitic terranes; (2) middle and late Paleozoic marginal basin systems; (3) Carboniferous and Permian paleogeography of island-arc terranes; (4) Permian and Triassic arc sequences and accretionary complexes; and (5) early Mesozoic convergent-margin paleogeography. Each section contains three to seven papers. The editors also have taken the time to compile a 12-page index.

The volume and many of the individual papers represent commendable efforts to integrate geology, geophysics, geochemistry, and paleontology into workable paleogeographic reconstructions. Taken together, these papers make a powerful case for the origin and evolution of these terranes as an arc system, developed in part on continental crust or close enough to a continent to receive continental detritus.

An overview paper by C.M. Rubin, M.M. Miller, and G.M. Smith includes descriptions and interpretations of related terranes along the North American margin north to the Brooks Range. One paper, by J. Charvet and six coworkers, includes specific discussion of the Blue Mountains in northeastern Oregon.

Most authors point toward North America as the source of continental detritus and continental geochemical signatures in the arc terranes and suggest an origin in the eastern Pacific (eastern Panthalassa) adjacent to the continent. However, the paper by C.H. Stevens, T.E. Yancey, and R.A. Hanger presents paleontologic evidence for a significant geographic barrier (deep ocean) separating North America from the Eastern Klamath terrane during the Permian.

An occurrence of Eastern Klamath terrane rocks in the northern Sierra Nevada is described in a paper by A.S. Jayko. E.A. Mankinen and W.P. Irwin summarize late Paleozoic and Mesozoic paleomagnetic constraints on paleogeographic reconstructions. Several papers describe rocks in western Nevada, the constraints they place on the nature and timing of events along the continental margin, and the implications for outboard terranes.

The book is a worthwhile addition to the library of any geologist working in Paleozoic or early Mesozoic terranes of western North America. It is available from the Geological Society of America, P.O. Box 9140, Boulder, CO 80301, and may be ordered by phone 800-472-1988 or 303-447-2020 or FAX 303-447-1133. □

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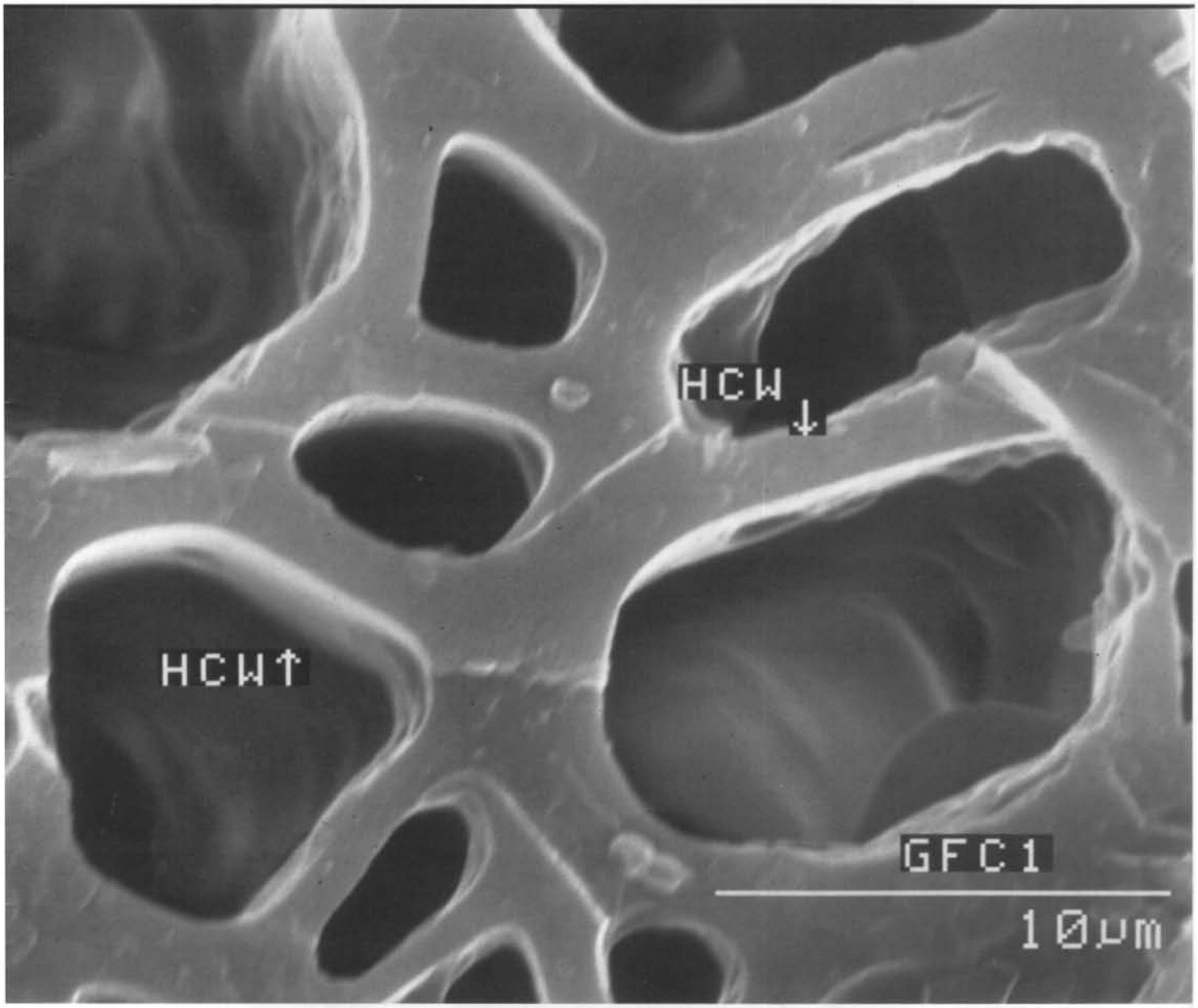


IN THIS ISSUE:

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

## Cover photo

Cell structure of carbonized wood as seen in a scanning electron microscope. The wood was carbonized in a recent forest fire in southern Oregon and shows evidence of homogenized cell walls (HCW). Ivan Gall, in his article beginning on page 109, investigates the value of HCW in fossil charcoal from sedimentary rocks as an indicator of ash-flow deposits.

# OIL AND GAS NEWS

### Drilling underway at Mist Gas Field

During July, Nahama and Weagant Energy Company of Bakersfield, California, began a multi-well drilling program at the Mist Gas Field, Columbia County, Oregon. The first well drilled, Columbia County 44-8-64, located in the SE¼ sec. 8, T. 6 N., R. 4 W., reached a total depth of 1,810 ft and is an indicated successful gas discovery that currently is suspended, awaiting production testing. The next well drilled, Columbia County 23-35-75, located in the SW¼ sec. 35, T. 7 N., R. 5 W., reached a total depth of 3,374 ft and was plugged and abandoned. Drilling operations are currently underway at the Columbia County 34-31-65 located in the SE¼ sec. 31, T. 6 N., R. 5 W. Taylor Drilling Company, Chehalis, Washington, is the drilling contractor.

### Production tests on gas wells

During July and August, Oregon Natural Gas Development Corporation and ARCO conducted long-term production tests on three gas wells located at the southern end of the Mist Gas Field. These wells, the ARCO CFI 23-15, the ARCO CFI 31-16, and the ARCO Columbia County 42-8, contain gas with a low BTU content and were tested to determine whether they are currently capable of economic utilization.

### NWPA elects board

The Northwest Petroleum Association (NWPA) announced the results of the elections of the Board for 1991-1992. The officers now are Lanny Fisk, President; Jack Meyer, Vice President; John Newhouse, Secretary; Vijai Shukla, Treasurer; and Barbara Portwood, Past President. Directors are Peter Hales, Western Washington; Phil Brogan, Eastern Oregon and Washington; Margene Hamer, Land; Beth-Karan Kaye, Legal; and Nancy Ketrenos and Dan Wermiel, At-large.

The NWPA is an organization of persons interested in oil, gas and geothermal energy resources in the Pacific Northwest. Meetings with a speaker are held each month, and an annual field symposium is held each fall. Contact the NWPA, P.O. Box 6679, Portland, OR 97228-6679, for further information.

### Recent permits

| Permit no. | Operator, well, API number | Location | Status, proposed total depth (ft) |
|---|---|---|---|
| 462 | Nahama & Weagant<br>Oregon 31-36-66<br>36-007-00023 | NE¼ sec. 36<br>T. 6 N., R. 6 W.<br>Clatsop County | Permit;<br>2,430. |
| 463 | Nahama & Weagant<br>CC 34-8-64<br>36-009-00288 | SE¼ sec. 8<br>T. 6 N., R. 4 W.<br>Columbia County | Application;<br>1,350. |
| 464 | Nahama & Weagant<br>CER 12-26-64<br>36-009-00289 | NW¼ sec. 26<br>T. 6 N., R. 4 W.<br>Columbia County | Application;<br>2,790. |
| 465 | Nahama & Weagant<br>CER 31-26-64<br>36-009-00290 | NE¼ sec. 26<br>T. 6 N., R. 4 W.<br>Columbia County | Application;<br>3,120. |
| 466 | Nahama & Weagant<br>CC 23-19-65<br>36-009-00291 | SW¼ sec. 19<br>T. 6 N., R. 5 W.<br>Columbia County | Application;<br>3,000. |
| 467 | Nahama & Weagant<br>Johnston 11-30-65<br>36-009-00292 | NW¼ sec. 30<br>T. 6 N., R. 6 W.<br>Columbia County | Application;<br>2,700. |

□

# Oregon's gold coast*

*by Gary Meier, 1625 Henderson Avenue, D-12, Eugene, Oregon 97403-2323*

*"Gold in Oregon's beach sands!"*—so announced the Oregon and California newspapers in the spring of 1853, leading to a rush that would soon have thousands of determined argonauts converging on Oregon's South Coast.

The spark that ignited the commotion occurred a couple of months earlier, when California-bound prospectors John and Peter Groslius discovered rich amounts of fine gold in a stretch of black sand at Whisky Run Creek, north of the Coquille River. The brothers Groslius tried to work their claim quietly, but, as is the nature of such things, word of their discovery soon got out, and the rush was on.

The beach at Whisky Run, previously a secluded place of solitude with only the sound of the surf to break the quiet, became a circus of boisterous activity in the summer of '53. Hundreds of claims were staked up and down the beach, and a raucous tent-and-shack city named Randolph sprang into being on the bluff above. Within weeks of the boom camp's establishment, it had stores, saloons, lodging houses, and restaurants.

Newspapers such as the San Francisco *Alta California* fueled the golden fire with claims that the Oregon beach miners were cleaning $75 to $100 a day from their sluice boxes. So glorious were the reports of the new-found bonanza that even sailors on the supply ships from San Francisco were not immune. When the schooner *Cecil* arrived at Port Orford loaded with provisions for the miners, nearly the entire crew abandoned ship to work the beach near Whisky Run. Though accurate records are lacking, the Oregon Department of Geology and Mineral Industries estimates that between $80,000 and $100,000 in gold was taken out of the original Whisky Run claim.

The beach gold was found in dark deposits of heavy sand—mineral concentrate which had originally washed down from the streams and creeks of the Coast Range into the ocean. Subsequent wave action during high tides and storms brought the mineralized black sand back onto the beaches. Unknown at the time, the gold-bearing deposits also contained platinum and chromite (chrome ore).

The gold was in the form of fine grains, unlike the large flakes and nuggets found inland. To capture this "flour" gold, beach miners used various imaginative methods. The most common device was a long, riffled sluice box. Water was run through the sloping trough, and at the top end black sand was shoveled in. The heavier gold caught in the riffles, while the lighter, finer particles washed down to the lower end of the sluice box. There, thin copper plates coated with quicksilver caught and held the gold (a process called amalgamation), allowing the other material to wash away. Most of the gold, however, was trapped in the riffles. William V. Wells, who visited the Whisky Run diggings, wrote: ". . . we found the bottom of the trough sparkling with innumerable minute specks of gold. . . . It was a crystal brook, with golden pavement."

Where creek water was unavailable on the beach, miners used water from the ocean. When the tide was low they set up operations in the shallow surf, laboriously shoveling black sand into their sluice boxes and washing it down with countless buckets of saltwater. As the tide rose, the men moved everything back in stages until they were at the high-tide line. Then they would slowly follow the tide back down as it receded.

Other South Coast gold discoveries followed the Whisky Run bonanza in that magical summer of 1853. Valuable claims were staked on the beaches north and south of the mouth of the Rogue River, and colorfully named gold camps grew overnight—Elizabethtown, Hogtown, Ophir. On the south side of the Rogue, amidst a profusion of sluice boxes and claim stakes, the tent city of Sebastopol sprang up, later called Ellensburg, and still later, appropriately, Gold Beach.

*Mining the beach north of Newport with an 1890's "Long Tom" sluice box. Photo courtesy Lincoln County Historical Society.*

Farther down the coast, beach gold operations were profitable at the mouths of the Pistol, Chetco, Winchuck, and Smith Rivers as well as the creeks in between.

North of the Rogue River, rich gold strikes were made in the black sand deposits at Euchre Creek (Ophir), the mouths of the Elk and Sixes Rivers, and in the long sweep of the Cape Blanco beach.

Joseph H. McVay, an Oregon Coast pioneer, mined beach claims from Port Orford to the Rogue River in 1854. He later wrote: "In passing along the coast one could see in every little rivulet that came gushing from the banks particles of shining gold, rolling along with the black sand, and it seemed that we had truly arrived at an El Dorado."

The problem with this beach El Dorado, however, was the capriciousness of the ocean. What the sea brings in, the sea takes out. It was a constant frustration to the beach miners to wake in the morning and find that the tides had wiped away their black sand deposits. Rich pay streaks were covered over with thick white sand or entirely swept back into the ocean.

* This article appeared first in the March/April 1991 issue of *Oregon Coast* and is reprinted here with permission of the author.

*The "Million Dollar Beach," south of Whisky Run Creek. Each rivulet showed the sparkle of gold in the sunlight in 1853.*

*Shallow black beach sands today, as shown here in Whisky Run Creek, are a far cry from the deep deposits of the 1850's—but they still contain traces of gold.*

At Whisky Run in the spring of 1854, just a year after news of the first Oregon Coast gold discovery leaked to the world, a great slashing storm hit the beach. It obliterated most of the black sand deposits, destroyed networks of sluice boxes and flumes, and left in its wake dunes of worthless, ordinary white sand. The rich Whisky Run strike was over. Although some mining continued with each new gold-bearing deposit through the years, the original bonanza was never repeated. The bluff city of Randolph was soon abandoned and relocated at another site. The miners scattered to other beaches to work their new claims or went a mile or two inland, where gold was being discovered in ancient elevated beach terraces.

Fortunately, the ocean often relented after sweeping away miners' black sand hopes, redepositing new stretches of valuable concentrate on South Coast beaches, where waiting miners worked feverishly to extract the golden treasure before it was again taken from them.

In 1890, Oregon historian Frances Fuller Victor visited Coos and Curry Counties and reported that beach gold mining was still paying "fair wages." A number of beach placer mines became well-known into this century as profitable enterprises, including the Kalamazoo Ocean Beach Mine at Ophir, the Sixes Beach Placer at the mouth of that river, the Collins Mine north of Wedderburn, and the Blanco Blacksand Mine on the beach at Cape Blanco.

Gold discoveries were made on the beach north of Newport in the mid-1890's and again in 1911. Beach mining activity slowed somewhat in the 1920's, though a number of Coos and Curry gold mines were producing good profits from shafts deep in the ancient beach terraces inland. Some of the gold-rich black sand in mines such as the famous Pioneer Mine off Seven Devils Road, the Chickamin, the Independence, and the Eagle Mines were from 3 to 10 ft thick and hundreds of feet long. Several Oregon Coast newspapers, particularly the *Port Orford News* and the *Curry County Reporter*, carried advertisements for national gold buyers.

With the depression in the 1930's came a resurgence in beach mining, and the shores of Coos and Curry Counties were again dotted with miners' tents and campfires. More than a few hard-pressed families survived those difficult times, at least in part, by the gold they carefully gleaned from beach black sand deposits.

It is estimated that several million dollars in fine gold was mined from Oregon's beaches from 1853 until World War II. During the war, all gold mining in the United States was temporarily halted by Order L-208, designed to divert gold miners into seeking copper and other metals needed for the war effort. The order was rescinded after the war, but the high cost of operating and the restrictive $35-per-ounce government-controlled gold price kept most of the mines from reopening. One notable exception was the Cape Blanco Beach Mine, run by Carl Hopping in the 1930's and by successive owners until the late 1960's.

Oregon's beaches still beckon recreational prospectors, though the deposits of black sand these days are thin and scattered. But with patience and a sharp eye, it is still possible to find "color" in your gold pan at many locations on the south coast. Although the Oregon Department of Geology and Mineral Industries has not made an estimate of coastal gold reserves, it has stated that deposits suitable for recreational prospecting will continue to form here and there along the coast.

And who knows when the great Pacific storm tides might again bring large pay streaks of black sand to Whisky Run? □

## Tips for beach prospecting

Black sand deposits on Oregon's beaches are not what they once were, but they can still be found and often contain particles of gold. Here are some likely places to prospect:

**Coos County**

- Sacchi, Agate, and Merchants Beaches—off Seven Devils Road, north of Bandon
- Whisky Run Beach—Seven Devils Road
- All beaches and mouths of streams between Bandon and the Curry County line north of Langlois

**Curry County**

- Cape Blanco—north and south beaches
- Beaches in area of Port Orford
- All beaches from Humbug Mountain south to the California border, especially near Ophir, Gold Beach, Hunter's Creek, Pistol River, and Chetco River

**Lincoln County**

- Beaches north of Yaquina Bay, from Newport to Beverly Beach State Park

Be watchful for claim markers on inland streams. Do not prospect on marked claims. If you use ocean water for panning, **face the ocean!** Be alert for sneaker waves and floating driftwood.

Good Luck! □

# Initial results from the 1990 geothermal drilling program at Santiam Pass, Cascade Range, Oregon.

*by Brittain Hill and George Priest, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97201-5528, and David Blackwell, Southern Methodist University, Dallas, Texas 75275*

**ABSTRACT**

Drilling of a 929-m geothermal assessment hole near Santiam Pass in the Oregon Cascades has provided new information on the thermal regime and geology of the High Cascades. An unequilibrated, maximum geothermal gradient of 120 °C/km occurs in the bottom 20 m of the hole, with presumed background gradients of ~60 °C/km measured in the lower 200 m. Mafic lavas and dikes are the dominant rock types in the core, and a K-Ar date of 1.8 Ma at the bottom of the hole is consistent with the observed paleomagnetic stratigraphy. Regional correlations with drill core data indicate that a fault with ~440 m vertical displacement is buried within 16 km west of the drill site and that vertical displacement on the Green Ridge fault zone 18 km east of Santiam Pass must exceed 1 km.

**INTRODUCTION**

A 929-m geothermal observation hole has been drilled at 4,800-ft elevation on the axis of the Oregon Cascade Range near Santiam Pass (Figure 1). The Santiam Pass site 77-24 was chosen to assess the geothermal resource potential along the axis of High Cascade volcanism away from major volcanic centers. The scientific goals of this project were to obtain tem-

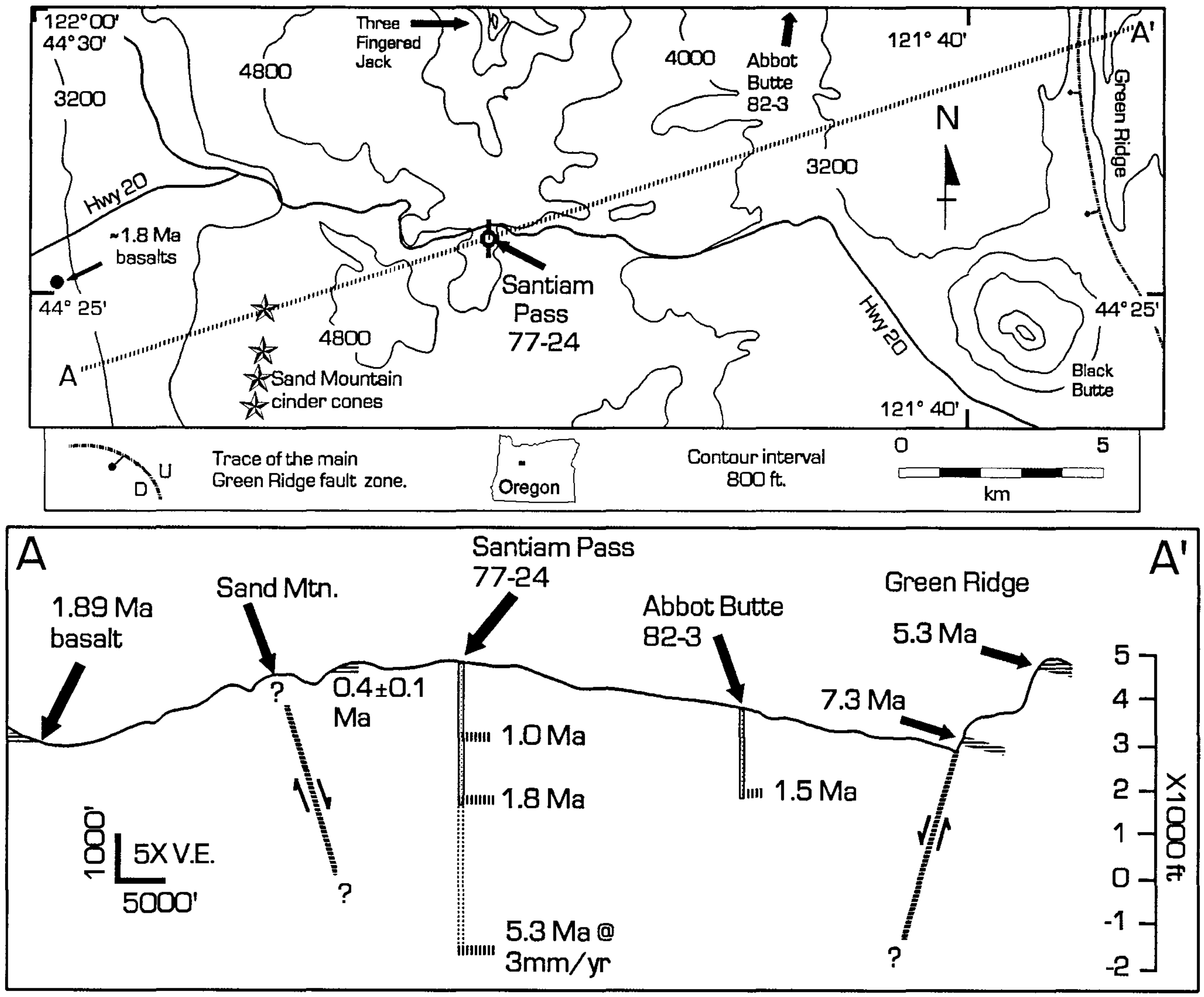


*Figure 1. Generalized location map and cross section of the Santiam Pass area of the Oregon Cascade Range. K-Ar dates from Armstrong and others (1975), Black and others (1987), Priest and others (1989), and this study. UNOCAL well Abbott Butte 82-3 projected into the cross section from north of the map area. Interval below 1.8 Ma in Santiam Pass 77-24 shows estimated depth to 5.3-Ma rocks using a deposition rate of 3 mm/yr.*

perature-gradient, heat-flow, hydrologic, and lithologic data that were not available from nearby shallow (~100-m) drill holes. Funding for this project was provided through a U.S. Department of Energy Geothermal Research Grant (DE-FG07-89ID12834) to the Oregon Department of Geology and Mineral Industries (DOGAMI) and a one-third cost share from Oxbow Geothermal Corporation of Reno, Nevada. This report summarizes the initial results of the drilling program. Final results will be published later in a DOGAMI open-file report.

## DRILLING OPERATIONS

The upper 140 m of the hole were rotary drilled in the fall of 1989 by Woytec Drilling Company. The upper 11 m were cased with 27.3-cm-inside-diameter (id) surface pipe, with 10.2-cm-id conductor cemented in the hole from the surface to 140 m. Diamond core drilling was done by Tonto Drilling Services under the direction of Oxbow Geothermal and DOGAMI. The hole was drilled from 140 m to total depth using HQ (10.2-cm-outside-diameter) diamond core rods, with >99.5 percent core recovery. Drilling operations commenced on August 10, 1990, and proceeded at an average daily rate of 28 m per day with no significant delays. Total drilling costs, including rotary drilling of the upper 140 m, were approximately $224,000; core drilling costs averaged ~$250/m, and rotary costs were ~$200/m. The hole was conditioned with heavy drilling mud and completed on September 14, 1990, with 4.8-cm-id, water-filled black pipe to total depth. Final site reclamation and abandonment will occur in the fall of 1991 after a final temperature log has been acquired.

## GEOTHERMAL DATA

Caliper and sonic logs were run before completion, and natural gamma-ray and temperature logs were run on September 19, 1990. An additional temperature log was run on September 27, 1990, which had a nonequilibrated bottom hole temperature of 24 °C. Bottom-hole temperatures measured during drilling were always less than 20 °C. Temperature recovery between the September 19 and 27 logs was about 1 °C to 1.5 °C between 160 and 180 m and below 900 m, with no change in temperature observed between 180 and 900 m. The lack of recovery between 180 and 900 m strongly indicates that this interval represents a zone of ground-water flow that resulted in rapid thermal reequilibration after drilling disturbance. Geothermal gradients measured on September 27, 1990 (Figure 2), were about 15 °C/km from 160 to 700 m, about 60 °C/km from 700 to 900 m, and about 120 °C/km from 905 to 920 m. Bottom-hole temperatures measured during drilling were used to constrain the geothermal gradients in the hole above 900 m. The hole will be logged at least once more before abandonment.

## GEOLOGIC DATA

Rocks encountered during drilling consisted of ~95 percent basalt to basaltic andesite flows and dikes, with ~5 percent volcanic sediments. Most of the units in the upper 514 m are basaltic andesites ($SiO_2 \approx 54$ percent) with reversed paleomagnetic directions. A thick (95-m) basaltic andesite flow at 502 m has a K-Ar age of 1.00±0.03 Ma (Table 1). Basalt and basaltic andesite flows with normal paleomagnetic directions extend from 514 to 643 m and overlie a ~0.5-m-thick paleosol. The paleosol caps a paleomagnetically reversed section of basaltic andesites, basalts, and intercalated volcanic sediments that extends to total depth (929 m). A porphyritic basaltic andesite flow at 928 m has a K-Ar age of 1.81±0.05 Ma (Table 1). Disseminated, low-grade zeolitic(?) alteration is also present in the lower ~100 m of the core. Detailed core studies, including petrographic analysis, measurement of thermal conductivity, and major and trace element analyses, are currently in progress.

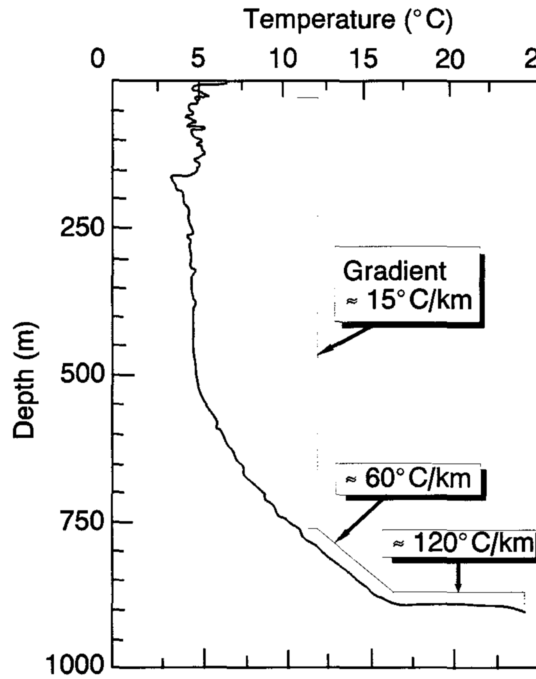


*Figure 2: Temperature-depth plot for Santiam Pass 77-24. Hole was logged 13 days after completion (September 27, 1990) with water-filled iron pipe.*

## REGIONAL CORRELATIONS

Mafic flows of about 1.8 Ma are exposed 16 km west of the drill site (Black and others, 1987), at elevations of ~3,200 ft (Figure 1). If these flows are correlative with the ~1.8-Ma mafic flows in the Santiam Pass core (and assuming the flows are horizontal), then there is a minimum vertical displacement of 440 m between these units. This displacement may be associated with the north-striking structure that apparently controlled emplacement of the Sand Mountain cinder cones (Figure 1) and is the most prominent tectonic(?) feature in that area.

Drilling by UNOCAL Geothermal near Abbot Butte (~3,600-ft elevation) encountered 1.5-Ma basalt at a depth of 748 m (Priest and others, 1989), which indicates no significant (≥100-m) vertical displacement between the Santiam Pass and Abbot Butte drill holes. Mafic flows of about 5.3 Ma are exposed 19 km east of the drill site at the top of Green Ridge (~4,800-ft elevation) (Smith, 1986), which represents the eastern margin of the High Cascade graben (Smith and others, 1987). Offset between the top of Green Ridge and the base of the well Santiam Pass 77-24 indicates that at least 1 km of vertical displacement is associated with the Green Ridge fault zone. Rates of deposition average 5 mm/yr in the Santiam Pass core, 3.5 mm/yr in the Abbot Butte core, and 3.2 mm/yr at Green Ridge. Under the assumption that there was continuous deposition of 3 mm/yr from 5.3 Ma to 1.8 Ma, 5.3-Ma rocks correlative with Green Ridge may be located >1 km beneath the bottom of Santiam Pass 77-24. Faulting at Green Ridge associated with the High Cascade graben may thus have involved >2 km vertical displacement.


## ACKNOWLEDGMENTS

Dick Benoit, Oxbow Geothermal, supervised the drilling operations and provided valuable support for overcoming many of the logistical and financial problem associated with this study. Gerald Black, DOGAMI, provided detailed lithology logs of the UNOCAL Abbot Butte hole. We thank Howard Ross, University of Utah Research Institute; Bob Spafford, Southern Methodist Uni-

Table 1. *Whole-rock K-Ar data, Santiam Pass 77-24. Isotopic ratios determined at Oregon State University, R. Duncan, principal investigator. Decay constants:* $\lambda_e = 0.581x10^{-10}yr^{-1}$, $\lambda_\beta = 4.962x10^{-10}yr^{-1}$, *and* $^{40}K/K_{total} = 1.167x10^{-4}$ *mol/mol.*

| Depth (m) | Sample weight (g) | K[1] (weight percent) | $^{40}Ar_{rad}$ $x10^{-12}$ mol/g | $^{40}Ar_{rad}$ (percent) | Age (m.y.) (±1σ) | Comments |
|---|---|---|---|---|---|---|
| 502 | 4.94 | 0.76 | 1.32 | 15.6 | 1.00±0.03 | Basaltic andesite flow at 1,647 ft |
| 698 | 4.93 | 0.66 | 1.04 | 6.1 | 0.91±0.06 | Basaltic andesite flow, Ar loss(?) |
| 928 | 5.13 | 0.45 | 1.41 | 9.1 | 1.81±0.05 | Basal basaltic andesite flow(?) |

[1] K determined by atomic absorption spectrometry at University of Oregon, C. McBirney, analyst.

versity; Peter Hooper and Richard Conrey, Washington State University; and Robert Duncan, Oregon State University, for their analytical support, and UNOCAL Geothermal for providing core from Abbot Butte 82-3. Discussions with Edward Taylor, David Sherrod, Gerald Black and Richard Conrey clarified many of the regional interpretations of this project.

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# Geologic maps released

Two new geologic maps that describe in detail the geology and natural-resource potential of a portion of the Owyhee region in eastern Oregon have been released by the Oregon Department of Geology and Mineral Industries (DOGAMI). In addition to gold and silver and minerals associated with hydrothermal mineralization, the studies identify basalt and previously unreported low-grade limestone among the mineral resources of the study areas.

**Geology and mineral resources map of the Vines Hill Quadrangle, Malheur County, Oregon,** by Howard C. Brooks. DOGAMI Geological Map Series GMS-63, one two-color geologic map, scale 1:24,000. Price $5.

**Geology and mineral resources map of the South Mountain Quadrangle, Malheur County, Oregon,** by James G. Evans. DOGAMI Geological Map Series GMS-67, two plates (one two-color geologic map, scale 1:24,000, and one sheet containing geologic cross sections and geochemical data). Price $6.

Production of the maps was funded jointly by DOGAMI, the Oregon State Lottery, and the COGEOMAP Program of the U.S. Geological Survey as part of a cooperative effort to map the west half of the 1° by 2° Boise sheet in eastern Oregon. The two quadrangles are located in the northwestern corner of the Boise Sheet, southwest of the city of Vale and along the Malheur River.

Along with the geologic maps and cross sections, the new publications include brief discussions of the geology, structure, and the mineral and ground-water resources. Results of geochemical analyses of samples are also presented in tabulated form.

The rocks exposed in the area reflect a geologic history that reaches back about 15 million years to the Miocene and are dominantly the products of volcanic activity. Later during the Miocene, which ended around 5 million years ago, and into the Pliocene epoch, tectonic and erosional effects produced basins and lakes that left sedimentary deposits behind. Hydrothermal activity related to volcanism or deep-reaching faults continues in the area even today.

Both publications are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland; Oregon 97201-5528. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

# DOGAMI needs volunteers

The Oregon Department of Geology and Mineral Industries (DOGAMI) will be expanding its sales office when it moves to the new State Office Building in late February 1992. The new sales/information center, which will be located on the ground floor of the new building, will feature natural resource and outdoor recreation publications, brochures, maps, computer data, and information from DOGAMI, other state agencies, federal agencies, and other sources.

Because of its proximity to the convention center, the Lloyd Center, and MAX, Portland's light-rail system, the new facility is expected to handle a greater volume of customers, including tourists, than in the current sales office—and we believe that people serving in the new facility will have a real opportunity to introduce both Oregonians and tourists to many of the natural wonders of the state.

We need volunteers to help staff the sales/information center. Volunteers will have opportunities to meet the public, answer questions, sell publications, help maintain the store, help with computers—all the things that will tell Oregonians and tourists about Oregon's natural resources and outdoor recreational opportunities.

If you are interested in becoming a DOGAMI volunteer, you may select the type of activity you want to do, your hours, and the days you will help us. You might consider working with a friend—or job sharing if you want to make a smaller time commitment. Training for the store will start in January. If you like people, have interest or expertise in some aspect of Oregon's natural resources such as geology, plants, wildlife, birds, or forestry, want to learn more about any such subjects, or just would like an opportunity to provide service to Oregonians and tourists, contact Beverly Vogt, DOGAMI, 910 State Office Building, Portland OR 97201, phone (503) 229-5580. □

# The case of the inverted auriferous paleotorrent—exotic quartzite gravels on Wallowa Mountain peaks

*by John Eliot Allen, Department of Geology, Portland State University, Portland, Oregon 97207-0751*

## INTRODUCTION

*"The Wallowa Mountains consist of a core of Triassic and Jurassic volcanic and sedimentary rocks that were intruded and deformed by Cretaceous(?) granodiorite intrusive rocks. After uplift and erosion unroofed the Cretaceous(?) batholith, the area was covered by Miocene basalt flows of the Columbia River Group. Further uplift and erosion, including intense sculpture by alpine glaciation, removed basalt from about a third of the range and gave it its present form"* (Weis and others, 1976, p. E-9).

While mapping in 1938 the contacts of basalt over granodiorite along the western ridges of the Wallowa Mountains, Herb Harper and I climbed up more than 1,000 m (3,500 ft) over a map distance of 4 km (2.5 mi) from the Lostine River, along Bowman Creek and past Chimney and Hobo Lakes to the summit height of 2,692 m (8,831 ft) of Lookout Mountain. Beneath the 46 m (150 ft) of basalt that caps the granite peak, we found a thick bed of quartzite-bearing gravels, cobbles, and giant boulders. These gravels have haunted me ever since.

## "TERTIARY GRAVELS"

Our description of this locality and the basal lava contacts elsewhere in the Wallowa Mountains was as follows:

*"The Columbia River flowed out upon and covered a gently rolling, late mature surface with a relief of from 500 to 1,500 ft. A rather deeply weathered granitic soil mantled the old terrain, and this thick weathered zone occasionally remains, as on the slopes northeast of Aneroid Lake and around the Great Northern Mines west of Glacier Peak. Gravels are found at several places along the contact. Just east of Lookout Mountain, a bed of early Tertiary stream gravels up to 30 ft in thickness lies upon the granite and under the basalt. It is composed of round, waterworn boulders, up to 3 ft in diameter, of quartzite, aplite, and other metamorphic and igneous types of rock. The quartzite boulders are nearly all scarred with crescentic chatter marks and make up over 20 percent of the bed"* (Smith and Allen, 1941, p. 19).

## "AURIFEROUS GRAVELS"

The incentive for this paper comes from Robert McKenzie of Pendleton, who several years ago described to me the Jim White Ridge Placer Mine, 11 km (7 mi) due west of Lookout Mountain, and who recently called to see if I could tell him who Jim White was and when the mining there had taken place. I couldn't, but I am hoping some reader may write and tell us.

In pursuing this, a reference (Weis and others, 1976) turned up that located seven other occurrences of quartzite gravels in the western Wallowa Mountains, distributed over an area of nearly 390 km$^2$ (150 mi$^2$) at elevations from 1,402 to 2,658 m (4,600–8,720 ft).

Table 1 and Figure 1 list and locate these high-level quartzite-bearing gravels mapped by the U.S. Geological Survey and the U.S. Bureau of Mines during the early 1970's in an investigation of the mineral resources of the Eagle Cap Wilderness. The gravels are discussed as follows:

*"Coarse boulder gravel occurs at several places in the Wallowa Mountains. Most outcrop areas cover only a few hundred square feet; a notable exception is on Jim White Ridge, where more than a square mile is underlain by gravel. All deposits are on a pre-Miocene erosion surface that was preserved beneath basalt flows of the Columbia River Group until Holocene erosion exhumed the underlying rock. Most deposits are on weathered and disaggregated batholithic rock at the edges of scattered basalt remnants along ridge crests.*

*"The boulders are as much as 60 cm (2 ft) in diameter and are typically very well rounded. Many show abundant percussion*

Table 1. *Occurrences of quartzite gravels in the western Wallowa Mountains. Compiled from Weis and others (1976)*

| | Name | Location | Elevation | Comments |
|---|---|---|---|---|
| 1. | Lookout Mountain | SW¼ sec. 21, T. 3 S., R. 43 E. | 2,692 m (8,831 ft) | Gravels at 2,637 m (8,650 ft) |
| 2. | Jim White Ridge placer | NE¼ sec. 21, T. 3 S., R. 42 E. (7 mi due W. of no. 1) | 2,073 m (6,800 ft) | Gravels 55 m (180 ft) thick, extend to NNW. for 2 mi along the top of the ridge |
| 3. | Threemile Creek | Sec. 10, T. 3 S., R. 42 E. (2 mi N. and 5 mi W. of no. 1) | 2,042 m (6,700 ft) | — |
| 4. | Burger Pass | Sec. 12, T. 5 S., R. 42 E. (10 mi S. and 3 mi W. of no. 1) | 2,377 m (7,800 ft) | — |
| 5. | Buck Creek | Sec. 10, T. 5 S., R. 42 E. (2 mi W. of no. 4) | 1,829 m (6,000 ft) | — |
| 6. | Bone Ridge placer | Center sec. 1, T. 3 S., R. 41 E. (4 mi NW. of no. 2) | 1,402 m (4,600 ft) | Quartzite boulders up to 0.6-m (2-ft) diameter |
| 7. | Cached Lake | SW¼ sec. 19, T. 5 S., R. 44 E. (on ridge to S. of lake) | 2,487 m (8,160 ft) | — |
| 8. | Elkhorn Ridge | NE¼ sec. 22, T. 4 S., R. 43 E. | 2,658 m (8,720 ft) | — |

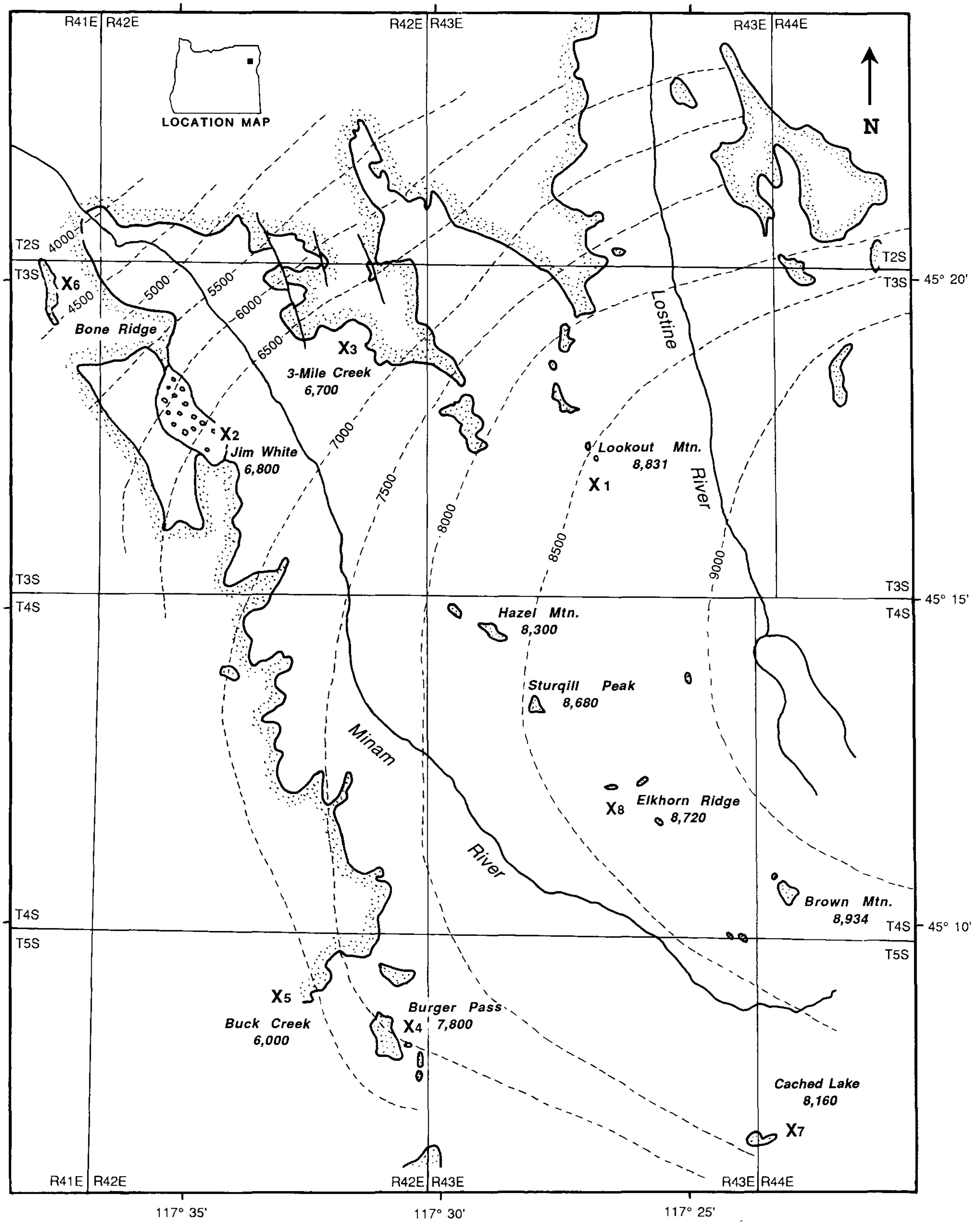


*Figure 1. Map of the western part of the northern Wallowa Mountains, showing the location of the contacts of basalt (fine stipple) over granodiorite and eight locations (X1-X8) of quartzitic gravels (circles at Jim White Ridge placer, X2) at these contacts. An attempt has been made to draw 500-ft contours upon this subbasalt surface. See also Table 1. After Weis and others, 1976, Pls. 1 and 2.*

*marks, indicating transport in a torrential stream. Several lithologies are represented. An exposure on the ridge south of Cached Lake contains representatives of most of the rock types found in the older Triassic rocks. In most deposits, however, more than 90 percent of the boulders are quartzite. F.C. Armstrong, who visited some of the occurrences with Weis during the field work, pointed out the striking similarity between some of these quartzites and some lower Paleozoic quartzites that have been mapped in southeastern Idaho. . . . No nearby source for the quartzite has been recognized. Other lithologies present include gneisses that resemble metamorphic rocks in west-central Idaho, but these are only sparingly represented.*

"Placer gold has been reported in association with some of the gravel deposits, but with the exception of the one on Jim White Ridge, the deposits contain insufficient yardage" (Weis and others, 1976, p. 15-16).

## DISCUSSION

What was the lower Miocene topography like? Was the uplift of the Wallowas uniform, or did it tilt, arch, or dome the area? Was this torrent a Snake or Columbia paleoriver? What is the provenance of the gravels? Can the gradient of a torrential paleoriver be distinguished from the difference in elevation resulting from arching and upfaulting of the Wallowa Mountains? Can widely scattered gravels be deposited by one river?

When in 1938 the Oregon Department of Geology and Mineral Industries mapped the northern Wallowas (Smith and Allen, 1941) on a Forest Service Atlas map with 500-ft contour intervals, it was impossible to contour the prebasalt topography in any detail. In 1970, 1971, and 1972 Weis mapped on 15-minute quadrangle maps published in 1954 and 1957, and these maps had contour intervals of 40 and 80 ft. Figure 1 is compiled from the maps of Weis and others (1976) to show the contacts beneath the Columbia River basalt, the location and elevation of the gravels, and contours drawn on the prebasalt surface.

Since the basalt covering a granodiorite topography would be thicker above a paleovalley, erosion during postbasalt uplift of the Wallowas would tend to invert the topographic relief. The quartzite gravels, therefore, should be and generally are found beneath basalt cappings along ridge crests. Lines of isolated basalt cappings on ridges in this part of the Wallowas generally trend northwesterly. If these represent inverted topography, they suggest northwest-trending valleys.

Rough contouring from the elevations at the basalt-granodiorite contacts taken from Weis and others (1976) indicates a low dome, which crests at the center of the east edge of the map in Figure 1 and whose slopes steepen toward the north, northwest, and southwest. This domal pattern suggests regional uplift, not stream gradients. Alignments of the ridge cappings is at least in part due to the present-day radial drainage pattern developed on this dome. The 500-ft contouring is too coarse to show paleoriver valleys and gradients.

The large size of the quartzite boulders and the polish and crescentic chatter or percussion marks upon them indicate violent rolling and impacts in swiftly moving torrents. The river or rivers must have been large with relatively straight courses, rather than meandering late-mature or old-age streams, in spite of the relatively subdued topography.

Geologists have always assumed that the quartzite component of the upper Miocene to Pliocene Troutdale Formation came down the Columbia River from the quartzites in the Precambrian Belt terrane of the Canadian Rockies. In Weis and others (1976, p. 16), Weis is mentioned as having learned of strikingly similar quartzites in southeastern Idaho, which might suggest a paleo-Snake or Salmon rather than Columbia River.

Such a paleoriver, however, is not indicated by work done farther north, in Washington: Fecht and others (1987) have established that it is not likely that the Snake or Columbia was here at this time, and Hooper and Swanson describe the eruption of Imnaha Basalt of the Columbia River Basalt Group in these words:

*"Thick lava flows filled deep valleys north and south of the Seven Devils/Wallowa Mountains divide . . . to a depth of nearly 700 m, with only the tops of the original mountains remaining above the lava plain"* (Hooper and Swanson, 1987, p. 202).

The widespread, scattered distribution of the quartzite gravel localities in the Wallowas at first suggests meandering across a flood plain, but this seems to be ruled out by the size of the boulders. Another possibility, that the scattered nature of the gravel localities indicates more than one river branch, seems to be ruled out by the distant source of the quartzites: they must have been deposited along the main stem of the ancestral river. This helps justify a third hypothesis: that only one great river periodically occupied braided channels within a broad valley.

Figure 2 presents a cartoon of this model: a broad valley in which violent floods deposited coarse gravels in braided channels of a heavily overloaded major river. Refinement of this "outrageous hypothesis" will need more field work, including, it is hoped, provenance studies of these gravels and the reported occurrences of similar gravels in Idaho, as well as the "auriferous gravels " in this and other parts of Oregon.

## CONCLUSIONS

Obviously, no firm conclusions can be drawn from this rather

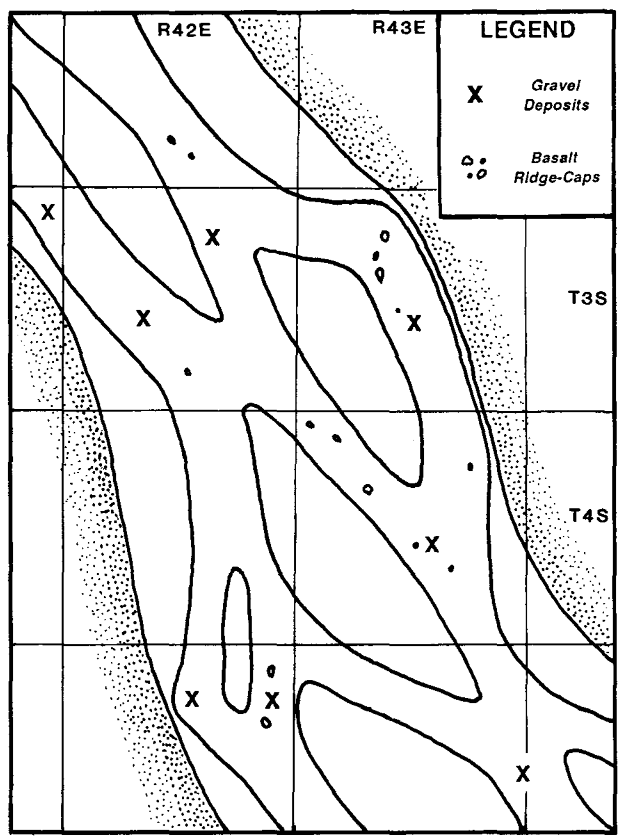


*Figure 2. Cartoon of the western part of the northern Wallowa Mountains in early Miocene time. The area is crossed by a broad paleovalley, occupied by the braided channels of a broad, northwest-flowing, and periodically torrential major river. Stipples indicates walls of valley, X the locations of gravels. Dots in valley indicate location of other basalt ridge cappings.*

skimpy and hypothetical study. No directional features (cross bedding, shingling, orientation of clasts, etc.) in the gravels have been described. No mention has been made of the presence or ingredients in a sand or silt fraction (except gold). No petrographic study has been done. Reported similar gravels in Idaho have not been investigated. Possible gradients and velocities have not been calculated by use of the Hjulstrom equation and curves.

Similar placers containing quartzite boulders have been mined for gold at numerous localities in northeastern Oregon. I once collected half a ton of silicified stumps of the fossil *Tempskya* from the old placer mine at the ghost town of Greenhorn, 48 km (30 mi) due west of Baker, near the summit of the Greenhorn Mountains, above 2,134-m (7,000-ft) elevation.

The main purpose of this paper is to stimulate further research on the interesting subject of the pre-Columbia River Basalt Group topography of northeastern Oregon.


### ACKNOWLEDGMENTS

I deeply appreciate the help of Paul Weis, Paul Hammond, Scott Burns, and especially Robert Carson, all of whom reviewed drafts of the manuscript, helped point out my mistakes, and made important suggestions.


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# Significant Oregon earthquakes in 1991

Oregonians felt two earthquakes in July. The first of these was located within the Gorda Plate off the coast of Oregon, 110 km (68 mi) west of Brookings. This Richter magnitude (M) 6.6 (Mw=6.7) event occurred at 7:50 p.m. local time on July 12, 1991, and was felt in many communities in western Oregon. The epicenter was at lat 42°7.28′N., long 125°50.82′W., with a focal depth estimated at 10 km. The focal mechanism indicates left-lateral strike-slip movement. Although the earthquake was felt over a wide area, no significant damage was reported. This is attributable to the fact that the epicenter was located so far out to sea.

The second earthquake was actually the second of a series of six earthquakes, but it was the only one of them that was felt. This (felt) event occurred at 2:04 a.m. local time on July 22, 1991, and was assigned a Richter magnitude of 3.5. The epicenter was at lat 45°38.94′N., long 122°50.46′W., with a focal depth of 17 km. These coordinates place the epicenter in the Tualatin Mountains west of Sauvie Island between the towns of Holbrook and Folkenberg in Multnomah County. Preliminary analysis of the focal mechanism indicates reverse-fault-type movement with a strong component of right-lateral strike slip.

The first earthquake of the series occurred before the "main shock," at 10:23 p.m. on July 21 and had a magnitude of 2.4. The four "aftershocks" occurred on July 22 at 2:11, 4:45, 5:28, and 9:34 a.m. with magnitudes ranging from 2.1 to 2.4. Some minor damage such as cracked plaster and broken glass was reported.

Earlier this year, on March 5, a magnitude 3.1 earthquake occurred across the Columbia River in Washington between Woodland and Vancouver. The epicenter was at lat 45°46.96′N., long 122°40.74′W. This earthquake occurred at 12:41 p.m. local time and was felt by some people in the Portland area.

These earthquakes serve as a gentle reminder that Oregon is indeed earthquake country, but they do not foretell an imminent damaging earthquake. The wide area over which a M=3.5 earthquake was felt strongly enough to awaken people indicates that many areas of the Portland metropolitan area respond strongly to low-level ground shaking.

Information about these earthquakes was obtained from the University of Washington and Oregon State University and by reviewing media reports and personal conversations. □

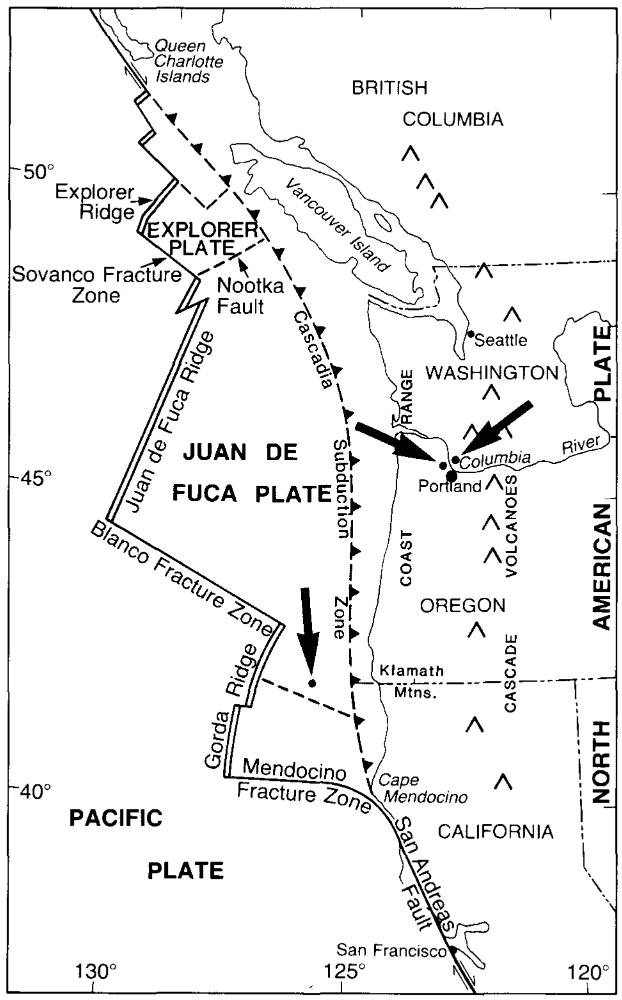


*Plate-tectonic map of the Pacific Northwest and the adjacent sea floor. Arrows indicate the locations of the earthquakes discussed in the report.*

## Senate bills address earthquake safety, drilling regulation

Senate Bills (SB) 96 and 888 were passed by the 1991 Legislature and have become law.

SB 96 establishes the Seismic Safety Policy Advisory Commission by statute, thereby making it permanent. It specifies membership to include eight state agencies, among them Building Codes, Geology, and Transportation, two members of the legislature, a structural engineer, a representative of school districts, one of utilities, and one member each of city government and county government. This wide array of membership is needed in policy guidance to address all three major aspects of earthquakes: risk identification, mitigation, and post-earthquake response. The commission is also directed to work as much as possible with existing institutions and agencies.

In addition, SB 96 gives the Building Codes Agency permissive guidance to consider rules for such things as requiring site-specific studies for large buildings, selective installation of accelerographs, a review of site-specific earthquake risk assessments, and public access to pertinent earthquake risk data.

Finally, the bill also provides for education in earthquake safety awareness in schools.

Senate Bill 888 affects permit fees for the drilling of oil and gas and geothermal wells in Oregon and the validity period of geothermal drilling permits. The bill provides that permit fees, to be set by the Governing Board of the Oregon Department of Geology and Mineral Industries, shall not exceed \$250 for a permit-application or permit-renewal fee and \$500 for an annual fee on active permits. It also provides that a geothermal permit shall remain valid for one year from the date of issue and may be renewed for a period of one year. □

## Hazard conference announced

A conference on "Coastal Natural Hazards—Science, Engineering, and Public Policy" will be held October 1-3, 1991, at the Hotel Newport at Agate Beach in Newport, Oregon. It is sponsored by the Oregon State University Extension Sea Grant College Program, the Oregon Department of Land Conservation and Development, the Oregon Department of Geology and Mineral Industries, the Oregon State Parks and Recreation Department, the Oregon Division of State Lands, and the Oregon Coastal Zone Management Association.

Earthquakes, beach and sea cliff erosion, flooding, landslides, tsunamis, coastal subsidence, sea level rise—these natural hazards affecting the way people live, work, and play on the Pacific Northwest coast will be the subject of the conference. The issues addressed will include what scientists and engineers are learning about these hazards and what their research implies for coastal residents, visitors, and the protection of public beaches and private property along the oceanfront.

The conference is aimed at policy makers and officials as well as people who own, develop, evaluate, or sell coastal property and people who are involved in public-interest groups.

The conference will begin on the afternoon of October 1 with a field trip to observe regional geology, erosion, landslides, shore protection, and earthquake evidence. On October 2, three all-day panels will focus on (1) earthquake, tsunami, and landslide hazards; (2) coastal processes and hazards related to erosion and sand transport; and (3) shore protection and engineering. The morning of October 3 will be occupied with presentations and focus groups on the policy implications of coastal hazards science and engineering.

Further information is available from Ginny Domka, Oceanography Administration Building 104, College of Oceanography, Oregon State University, Corvallis, OR 97331-5503, phone (503) 737-3771 (mornings only). □

## EEZ symposium to be held in Portland

The 1991 Exclusive Economic Zone (EEZ) Symposium will be held in Portland on November 5-7 at the Portland Hilton Hotel under the title "Working Together in the Pacific EEZ." It is sponsored by the USGS-NOAA Joint Office for Mapping and Research (JOMAR) and the Association of American State Geologists and will be hosted by the Oregon Department of Geology and Mineral Industries (DOGAMI).

This is the fifth in a series of biennial symposia held since the issuance of the EEZ Proclamation in 1983. Previous symposia have been held in the Washington, D.C., area and have focused on EEZ mapping and research from a national perspective. The intention of the 1991 Symposium is to begin the process of refining the specific interests and activities within each of the EEZ subregions (East Coast, Gulf of Mexico, West Coast, Alaska, and Islands) and to involve to a greater extent the active mapping and research programs in those geographical areas in the mission of JOMAR.

The symposium will focus on working relationships and partnerships for research and mapping in the Pacific EEZ and how they affect implementation of the ten-year national effort to characterize the seafloor/subsoil of the EEZ. Specific objectives include (1) to identify priorities for seafloor mapping and research, primarily in the Pacific EEZ but in other regions as well; (2) to recommend specific products and services necessary to meet these priorities; (3) to summarize progress in seafloor mapping and research in the Pacific EEZ; (4) to foster discussion regarding the management and dissemination of data and information relating to the seafloor of the EEZ and to identify requirements for standardization and exchange of digital mapping products; and (5) to recommend regional implementation and coordination approaches, including cooperative projects and the roles of the federal, state, academic, and private sectors.

An exhibit of research and mapping results is planned as an integral part of the symposium. Space is available, and interested participants with displays, exhibits, or posters are encouraged to contact the following for further information: USGS-NOAA Joint Office for Mapping and Research (JOMAR), 915 National Center, Reston, VA 22092, phone (703) 648-6525.

A block of rooms has been reserved at the Portland Hilton Hotel at \$60 per night for singles and \$80 per night for doubles. Registration deadline for the blocked rooms is October 4.

A detailed agenda, lists of workshop chairpersons, speakers, and exhibits, and other logistical information will be mailed to all who have preregistered by October 20, 1991. Further technical information is available from Millington Lockwood at JOMAR, phone (703) 648-6525.

Registration information is available from Greg McMurray at DOGAMI, 1400 SW 5th Avenue, Room 910, Portland, OR 97201-5528, phone (503) 229-5580. □

## GSA announces annual meeting

The Geological Society of America (GSA) will hold its annual meeting and geoscience exhibition October 21-24, 1991, in the new convention center at San Diego, California.

The theme of this year's meeting is "Global Perspective," and much of the program will be devoted to topics of global change, natural disasters, and the limits of natural resources.

For further information on transportation, housing, and program, contact GSA Headquarters, P.O. Box 9140, Boulder CO 80301, (303) 447-2020 or 1-800-472-1988, FAX 303-447-1133. For air transportation, Cain Travel Group is the official travel agency for the meeting and can be reached at 1-800-346-4747 (MDT business hours). Visitor information is offered by State of California, Visitor Packet, 1-800-862-2543; and San Diego Visitor Information Center, 11 Horton Plaza, San Diego CA 92101, (619) 236-1212. —*GSA news release*

# Cell wall structure of carbonized wood as related to ignimbrite deposition

## A Robert Ruhl Learning Fellowship Research Project

*by Ivan K. Gall, Department of Geology, Southern Oregon State College, Ashland, Oregon 97520*


### ABSTRACT

Cell-wall structure of carbonized wood fragments from ancient and recent sedimentary deposits was examined in a study using a scanning electron microscope. It has been determined that homogenization of the cell walls, caused by fusion/disappearance of the middle lamellae, is not necessarily indicative of ignimbrite deposition. Four examples of homogenized cell-wall structure were found to exist outside an ashflow depositional environment. A concretion from a nearshore marine mudstone in the Upper Cretaceous Hornbrook Formation yielded a carbonized wood fragment with homogenized cell-wall (HCW) structure. A sample from a log found in its growth position and buried by 2.25 m of hot air-fall tephra, yielded HCW structure. A 2-mm-diameter sample from the Mount St. Helens blast deposit of the May 1980 eruption, yielded both a HCW zone and a zone with the middle lamellae distinctly evident. Three samples of carbonized wood taken from recent forest fires have yielded HCW structure. Samples taken from lacustrine and volcaniclastic deposits contained carbonized fragments with no cell structure evident, due to some combination of size, fragility, burial, compaction, contact metamorphism, or silicification of the wood fragments. The temperature at which this homogenization occurs is under investigation but is believed to occur at approximately 300 °C.


### INTRODUCTION

This research project, funded in part by a Robert Ruhl Learning Fellowship, was conducted during the school year of 1990-91 at Southern Oregon State College. The research attempted to determine whether the presence of homogenized cell-wall (HCW) structure found within fragments of carbonized wood is uniquely indicative of ashflow deposition.

The homogenization, presumably the result of thermal fusion of the middle lamellae, primary, and secondary cell walls, takes place at temperatures exceeding 300 °C (Cope and Chaloner, 1980). McGinnes and others (1974) noted that high doses (655 millirad) of gamma radiation elicit the same fused cell wall structure as that found in carbonized wood.

Beall and others (1974), Cope and Chaloner (1980), and McGinnes and others (1974) all noted the apparent fusion, or homogenization, of the cell walls of carbonized wood of many different species. In coalified woody tissue, the middle lamellae are present up to the medium volatile bituminous rank of coal (Cope and Chaloner, 1980). As charcoal is largely unaffected by fungi or other wood-destroying organisms and because anatomical features remain intact during carbonization, the type of wood usually can be identified (Koeppen, 1972).

If fusion of the cell walls can be accomplished by radiation, the question arises as to whether other mechanisms might also produce the same effect. If so, the presence of HCW structure in a volcanic ash deposit may not be conclusive evidence that the deposit is of ash-flow, as opposed to ash-fall, or other, origin. To evaluate this hypothesis, twenty samples were collected from several environments in the southern Oregon area, and samples from Mount St. Helens and from Rock Mesa in Deschutes County, Oregon, were provided by the U.S. Geological Survey. The samples were then examined on a Hitachi S-2100 scanning electron microscope (SEM).

### SAMPLE COLLECTION

Seven samples were collected from unequivocal ash-flow deposits from the eruption of Mount Mazama that created Crater Lake. The samples were collected primarily along road cuts of State Highways 138 and 230, northwest of present-day Crater Lake. Muffler (1989) mapped a portion of the sampled area as the Mazama ash flow, and no observations in the field indicated that any of the deposits had been reworked by water, which might have transported fragments of carbonized wood into the deposits. The beds were composed of loose, poorly sorted ash, pumice, and rock fragments (predominantly of basaltic composition) with no distinct layering or bedding (Figure 1).

*Figure 1. Deposit of the Mount Mazama ash flow.*

Samples GMC 1-7 were collected from the Mount Mazama ashflow. The fragments of carbonized wood, some from carbonized logs up to 25 cm in diameter, displayed prominent growth rings.

Three samples were collected from Shale City, east of Ashland, Oregon. This lacustrine deposit is composed of a finely laminated volcanic ash with interbedded, more resistant, carbon-rich layers. Due to the emplacement of nearby silicic dikes, kerogen was mobilized within the sediments, and some mercury mineralization has occurred in the vicinity.

The samples collected from Shale City (GSC 1-3) consisted of a brilliantly glossy, vitrain-like carbon (as defined by Hickling and Marshall, 1932). It appears homogeneous to the naked eye, occurs in thin bands, and develops a prominent cleavage. No growth rings or wood structure was evident within the vitrain-like carbon. Carbonized leaf imprints are abundant in the deposit.

Two samples (GHC 1-2) were collected from a lower member of the Upper Cretaceous Hornbrook Formation, as mapped by Nilsen and Barats (1984), at an outcrop along Interstate Route 5, 0.5 mi north of the Mount Ashland access road turnoff. The samples were taken from a carbon-rich mudstone deposited in a nearshore marine environment. The carbonized fragments were very small and friable and showed no plant structure. A partially silicified fragment of carbonized wood was found within a concretion.

Samples of carbonized wood were collected from three locations within the Colestin Formation, a volcaniclastic sequence of inter-

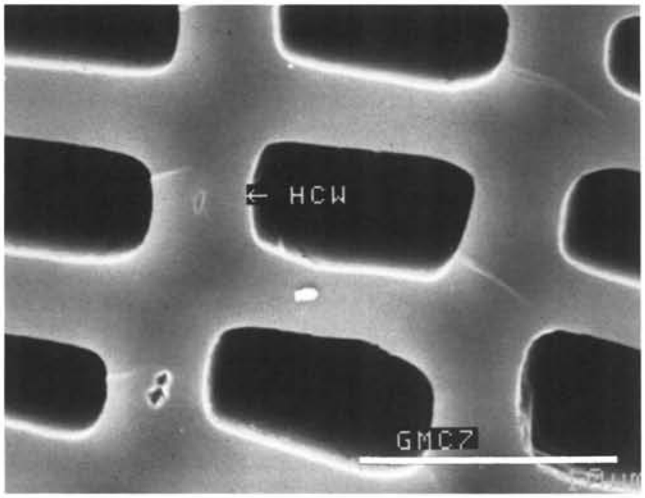


*Figure 2. HCW structure in carbonized wood of the Mount Mazama ash flow (Sample GMC 7). Bar = 10 μ.*

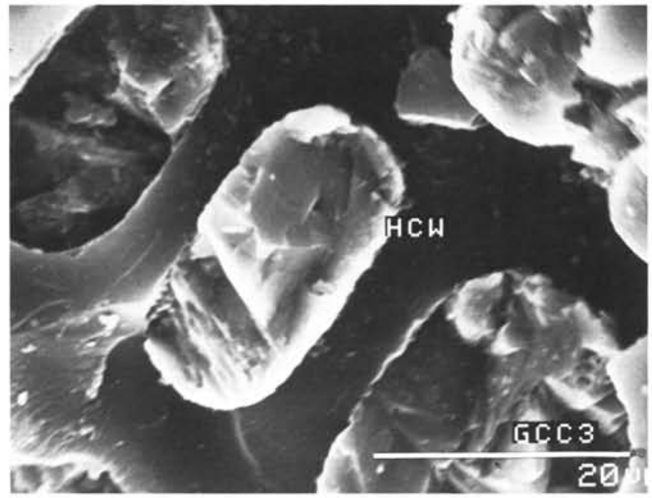


*Figure 4. HCW structure in carbonized wood of the Colestin Formation (Sample GCC 3). Bar = 20 μ.*

bedded mudflows, ash flows, and air-fall deposits. The first location sampled (GCC 1) was at the junction of the Mount Ashland access road and the Colestin Road turnoff, from a bed mapped by Bestland (1985) as his informal member Tct, a white crystal tuff. Bestland describes this deposit as an ash-flow tuff, citing the presence of HCW structure of contained wood fragments as good evidence of ignimbrite deposition. Samples collected here were lapilli-sized, partially silicified, and of a planar nature, being less than 1 mm thick.

The second location sampled (GCC 2) was at a benched road cut on Interstate Route 5, 2.7 mi north of the California border. Pieces of carbonized, silicified logs were collected from a 5-ft-thick, blocky, jointed, welded ash-flow deposit, also containing flattened pumice fragments. The samples showed indistinct growth rings.

The third sample of the Colestin Formation was collected on the east side of the Interstate Route 5 road cut at the Siskiyou summit, again from Bestland's (1985) informal Tct member. The sample (GCC 3) was taken from a carbonized, partially silicified log with distinct growth rings.

Two samples were provided for the study by the U.S. Geological Survey. One sample was collected from the Mount St. Helens blast deposit and consisted of a mass of inhomogeneous, loose, juvenile, and accidental material. The sample (H87-15A1-2) was taken from a partially charred fragment of wood. The second sample (GU 1) was collected from a charred log found in growth position near Rock Mesa in Deschutes County, Oregon. The log that was found near an eruptive vent had been buried by 2.25 m of coarse, hot air-fall tephra. A radiocarbon age of 2,150±150 years was obtained from the sample.

Three samples of charred wood (GFC 1-3) were collected near Ashland from forested areas recently burned by fires. Growth rings were evident in all three samples.

One sample of silicified wood (GS 1) was examined to determine how the process of silicification may effect cell wall structure. To view an undamaged middle lamella, one sample of raw wood (GRW 1), neither carbonized nor silicified, was examined.

## SAMPLE PREPARATION

The samples were mounted on specimen stubs, with a conducting carbon paint as an adhesive, and in most cases oriented so as to give a cross-sectional view of the cell wall structure.

The carbonized pieces of wood have low resistivity, and sputter coating the samples with gold is not necessary (Beall and others,

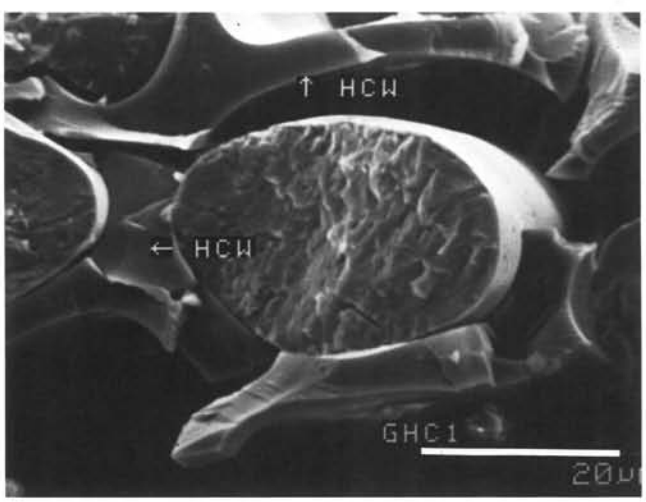


*Figure 3. HCW structure in carbonized wood from the Hornbrook Formation, found within a concretion (Sample GHC 2, mislabeled GHC 1). Bar = 20 μ.*

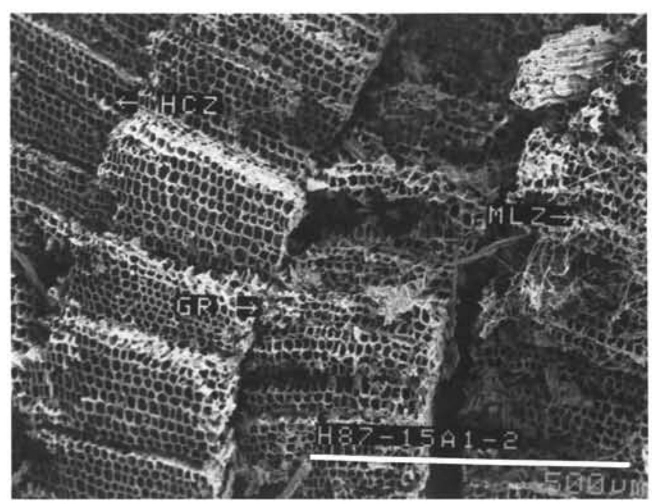


*Figure 5. Sample of partially carbonized wood from the Mount St. Helens blast deposit, showing a homogenized-cell zone (HCZ), a zone with middle lamellae still present (MLZ), and the curvature of growth rings (GR) (Sample H87-15A1-2). Bar = 500 μ.*

1974). Ali and others (1990) found that wood carbonized at 575 °C was sufficiently conductive so as not to require coating. Because coating the samples enhances the resolution and reduces charging that can lead to image distortion, most samples were coated for 1.5 minutes, with a depositional current of 15 milliampere, on an Emscope SC500 sputter coater.

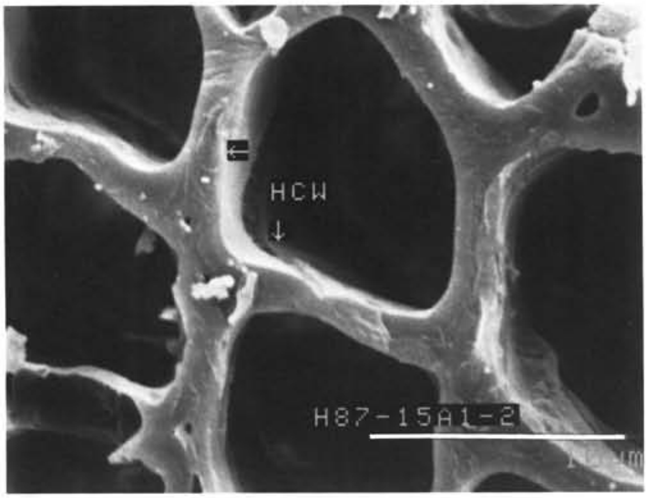


*Figure 6. HCW structure in carbonized wood of the sample shown in Figure 6. Bar = 10 μ.*

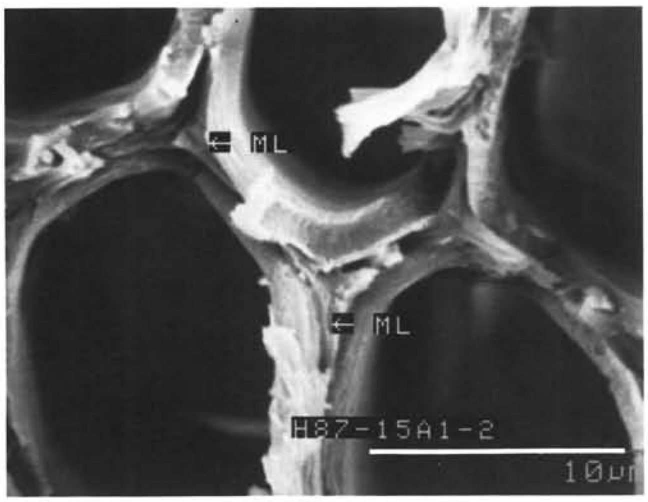


*Figure 7. Middle lamellae still present in carbonized wood of the sample shown in Figure 6. Bar = 10 μ.*

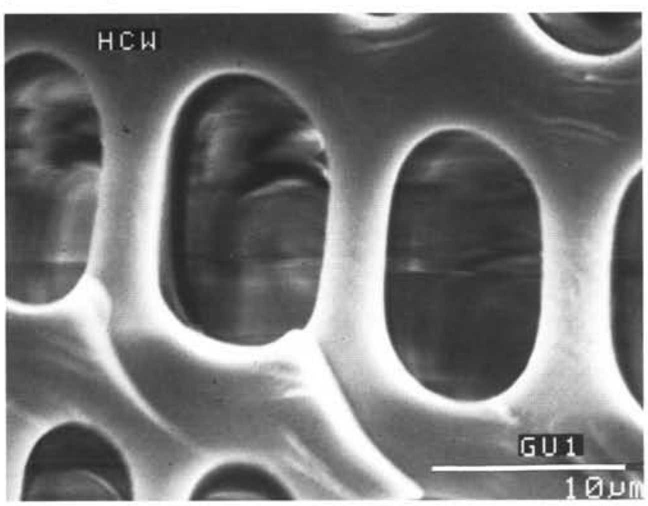


*Figure 8. HCW structure in carbonized log found in growth position at Rock Mesa (Sample GU 1). Bar = 10 μ.*

## SAMPLE EXAMINATION

All of the samples examined from the Mount Mazama ash-flow deposits (GMC 1-7) exhibited HWC structure (Figure 2). The orientation of these samples was facilitated by the presence of growth rings, and all samples showed well-preserved cell structure due to their young age and lack of deep burial and compaction.

The three samples from the Shale City lacustrine environment (GSC 1-3) displayed no preservation of cell structure. It is believed that the original size of the plant fragments incorporated into the sediment was too small for cell structure to survive burial, compaction, and possibly the heating episode accompanying the emplacement of nearby silicic dikes.

The sample of carbonized wood from the marine mudstone (GHC 1) exhibited no cell structure. Here again the small size of the original plant fragments, combined with burial and compaction, erased all evidence of the cell walls and middle lamellae.

The fragment of carbonized wood found within the concretion (GHC 2) featured homogenization of the cell walls (Figure 3). This is the first indication that carbonized wood fragments with homogenized cell wall structure exist outside a depositional environment other than that of an ash flow. It is believed that the formation of the concretion around the carbonized wood fragment was sufficient to preserve cell structure from destruction due to compaction attending burial.

Samples from the Colestin Formation collected at road cuts along the Mount Ashland access road (GCC 1) exhibited no recognizable cell wall structure. The samples were too small or too fragile to survive the burial and compaction.

Samples from the Colestin Formation, collected on Interstate Route 5 at the benched road cut (GCC 2), showed very indistinct cell wall structure. It was not evident as to whether the middle lamellae were present. The samples were silicified, and the silicification, combined with burial and compaction, seems to have obscured the cell structure.

Samples collected from the Colestin Formation at the Siskiyou Pass summit (GCC 3) exhibited cell wall homogenization (Figure 4). These samples were also silicified, but it is believed that the more readily apparent growth rings indicate that the wood has not been subjected to such large degrees of compaction or silicification.

Sample H87-15A1-2 from the Mount St. Helens blast deposit yielded a zone with homogenized cell walls and a zone of cell walls with the middle lamellae intact (Figures 5-7). These two zones were separated by a transitional zone in which the middle lamellae became more apparent toward the center of the tree, as evidenced by the curvature of growth rings.

It is interesting to note that this transition occurred over a distance of approximately 2 mm, suggesting that the occurrence of homogenized cell wall structure within a given deposit is variable over very short distances. Of considerable importance may be the exact circumstances under which the fragment of wood is incorporated into the deposit. A large heat sink may be present in the form of large, cold boulders or cooler exposed bed rock. These may absorb the heat of a hot deposit at a rate rapid enough to hinder the carbonization process of any wood fragments in the immediate vicinity. In contrast, a deposit of dense ash barely at a temperature sufficient to fuse the cell walls may remain hot long enough to thoroughly char the wood.

Sample GU 1, the charred log found in growth position, yielded HCW structure (Figure 8). Here is a third example of HCW structure occurring in a deposit (hot air-fall tephra) other than that of an ash flow. The sample examined came from very near the center

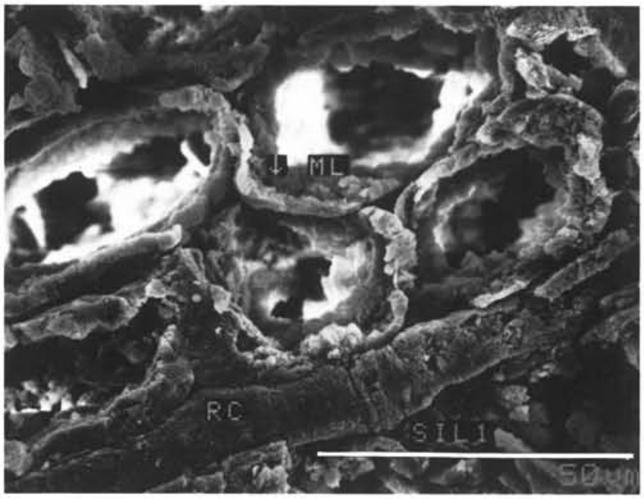


*Figure 9. Comparison sample showing effects of silicification on uncarbonized wood. Middle lamellae (ML) are still present (Sample GS 1 [=SIL 1]). RC = ray cell. Bar = 50 µ.*

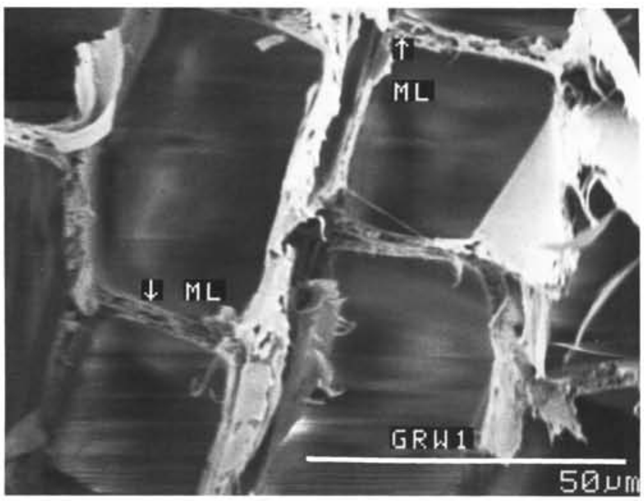


*Figure 10. Comparison sample showing distinct middle lamellae (ML) in uncarbonized, unsilicified, raw wood (Sample GRW 1). Bar = 50 µ.*

of the tree, as evidenced by the small radii of the growth rings. This fusion of the cell walls at the center of the tree is good evidence that the tephra fall was initially very hot, possibly due to its location near the erupting vent, or that it cooled very slowly, allowing a complete carbonization process to occur.

The three samples of charred wood collected from areas burned by recent forest fires (GFC 1-3) all yielded HCW structure (cover photo). This is a fourth instance in which homogenized cell walls exist in an environment other than that of an ash flow. Forest fires caused by lightning strikes and volcanism have been common as far back as the Paleozoic period (Komarek, 1972). As charred fragments of wood can later be incorporated with ash and other materials in volcaniclastic sediments, confusion between ash-flow deposits and those originating from debris flows or volcanic blasts becomes a distinct possibility.

A difficult problem arises with the sample preparation methods of the partially silicified fragments of carbonized wood. The replacement of the carbon with silica necessitates coating the samples with gold to enhance the conductivity and resolution and to reduce the effects of charging. The silicified samples fracture irregularly across the cell structure and thus leave almost no chance for the occurrence of visible cell structure. Instead of breaking the sample, grinding was tried to achieve a smooth surface for a cross-sectional view of the cell walls. However, the process done with grinding compound on a glass plate appeared to obscure the cell structure with respect to SEM viewing.

The examination of the silicified sample of wood indicated that in this particular case the silicification process did not cause the disappearance of the middle lamellae (Figure 9). The raw wood sample (GRW 1) exhibited excellent cell structure, with the middle lamellae readily apparent (Figure 10).

## CONCLUSION

The presence of carbonized wood fragments with homogenized cell walls has been found not to be uniquely indicative of ash-flow deposits. Homogenized cell wall structure has been found in deposits of a nearshore marine mudstone, the Mount St. Helens blast deposit, a log buried by a hot air-fall tephra, and in products of recent, subaerial forest fires. It is possible that other depositional environments containing sediments derived from areas in which forest fires occurred will also contain fragments of carbonized wood with homogenized cell wall structure. As the range of forest fire temperatures is 980-1,650 °C (oral communication, Bill Fransden, Intermountain Fire Science Laboratory, 1990), it would not be surprising to find HWC structure in forest-fire-burned fragments incorporated into a variety of sedimentary and volcaniclastic deposits.

## ACKNOWLEDGMENTS

The author would like to express gratitude to Dr. William Purdom, Professor of Geology, Southern Oregon State College, for his assistance and guidance throughout the duration of the research. Also deserving thanks are Doctors D'Allura and Elliott, Professors of Geology, and Doctors Southworth and Nitsos, Professors of Biology, all of Southern Oregon State College. Mr. Marvin Couchland of the U.S. Geological Survey in Vancouver, Washington, deserves thanks for providing samples that were of great value for this study.

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Muffler, L.J.P., 1989, South Cascades arc volcanism, California and southern Oregon: American Geophysical Union Field Trip Guidebook T312, p. 38. *(Continued on page 118, **Gall—Appendix**)*

## Earth science gains support*

Precollege earth science education received a strong sign of interdisciplinary support from the Council of Scientific Society Presidents (CSSP).

At their fall 1990 meeting in Washington, D.C., the Council members unanimously adopted a resolution recommending that substantial study of the geosciences be made a part of the precollege curriculum in the U.S. and that geoscience be acceptable as a laboratory science for college admission along with biology, chemistry, and physics. The resolution was drafted by Chip Groat, American Geological Institute Executive Director, and introduced by Bonnie Brunkhorst, President, National Science Teachers Association.

CSSP is an organization of elected officers of 57 scientific societies spanning the physical, mathematical, and life sciences. Since 1973, CSSP has served as a strong national voice in support of science and science education and as a forum for open, substantive exchanges on current scientific issues.

For further information, contact R. Eric Leber, Executive Director, Council of Scientific Society Presidents, 1155 16th Street NW, Washington, DC 20036, phone (202) 872-4452.

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### *Resolution on Teaching Geoscience at the Precollege Level*

Whereas an understanding of the earth's land, water, and atmospheric systems that control our environment and supplies of resources is important to all citizens; and

Whereas the distribution, development, and use of energy and mineral resources around the world have a significant influence on the economy of the United States and our foreign policy; and

Whereas the inhabitability of our cities and coasts and the productivity of our agricultural lands and oceans may be strongly influenced by global climatic change, the disposal of wastes, and the protection of our water supplies; and

Whereas the United States must attract a much larger number of students into scientific careers, and the study of geoscience can provide an effective way to demonstrate the relevance of science to issues that interest and are of concern to students;

Therefore be it resolved that the Council of Scientific Society Presidents strongly recommends that substantial study of the geosciences (e.g., soil science, geology, meteorology, oceanography, astronomy) be made a part of the pre-college curriculum in the United States middle and high schools and that its status as a laboratory science be acceptable for college admission along with biology, chemistry, and physics.

Be it further resolved that geoscience shall be one of the themes for the teaching of science in the elementary schools in our country.

***Adopted by The Council of Scientific Society Presidents December 5, 1990.***

## Earth-science education tools

The following annotated list was compiled by Julie Jackson of the American Geological Institute (AGI) and is reprinted here from the spring 1991 issue of *Blueline*, the newsletter of the American Association of Earth Science Editors (AESE). We hope that you will find this list useful and share it. For the geoscience professional, Jackson adds: "If you ever talk with school or youth groups, SEPM's *Sedimentary Geologist's Guide* . . . and AGI's *Resources* are especially good sources."—*Ed.*

**A Sedimentary Geologist's Guide to Helping K-12 Earth Science Teachers: Hints, Ideas, Activities, and Resources**, edited by Molly F. Miller, R. Heather Macdonald, Linda E. Okland, Steven R. Roof, and Lauret E. Savoy. The Society for Sedimentary Geology (SEPM) published this useful book in 1990 to encourage geologists to get involved in earth-science education. The book has four sections: "Hints for Successful Class Visits," "Activities for Teachers," "Field Trips and Larger Scale Educational Activities," and "Resources." Order from SEPM, PO Box 4756, Tulsa OK 74159, (918) 743-9765: tape-bound book, 91 pages, $5 plus $1.90 postage/handling.

**Earth Science Investigations**, edited by Margaret A. Oosterman and Mark T. Schmidt. AGI published this collection of activities for grades 8-12 in fall 1990. The 26 activities were developed by teachers, reviewed by scientists, and tested with students. Each hands-on exercise provides the concepts, vocabulary, and worksheets that students need to complete it, plus an answer key when applicable. Order from AGI, 4220 King Street, Alexandria VA 22302, (703) 379-2480: spiral-bound book, 231 pages, $34.95 plus $4 postage/handling. [See also our earlier announcement in the March 1991 issue of *Oregon Geology*, page 43.—*Ed.*]

**Earth Science Research Activities**, by James Scannell. Published in 1988, the book is one of four in the series "Explorations in Science." It contains 50 ready-to-use individual and group enrichment activities for grades 8-12. Each has been tested and includes a teacher's guide and answer key. Order from Alpha Publishing Company, 1910 Hidden Point Road, Annapolis MD 21401, (301) 757-5404: spiral-bound book, 273 pages, $35 plus $3.50 postage/handling.

**Resources for Earth Science Teachers, 1991**, lists 43 sources of earth science reference and enrichment materials including catalogs, publication lists, teacher packets, books, and journals. To get a copy, contact AGI, National Center for Earth Science Education, 4220 King Street, Alexandria VA 22302, (703) 379-2480.

**Earthquakes: A Teacher's Package for K-6**, a six-unit book, was developed by the National Science Teachers Association (NSTA) with a grant from the Federal Emergency Management Agency (FEMA). It is a complete earthquake curriculum containing activities, lesson plans, line masters, and background information. Order from FEMA, Earthquake Program, Attention Marilyn MacCabe, 500 C Street SW, Washington DC 20472: one free copy to schools (while supplies last). Order additional copies from NSTA (address below, next item): $15 plus $2.50 postage/handling.

**Earth: the Water Planet**, a book of readings and activities for middle-grade teachers, resulted from a joint project of Horizon Research, Inc., and AGI. Order from NSTA, 1742 Connecticut Avenue NW, Washington DC 20009, (202) 328-5800: $16.50 plus $2.50 postage/handling.

**For Spacious Skies Program** is a teacher activity guide for grades K-8. Order from For Spacious Skies, 54 Webb Street, Lexington MA 02173, (617) 862-4289: $6.

**How to Construct a Paper Model Showing the Motion That Occurred on the San Andreas Fault During the Loma Prieta, California, Earthquake of October 17, 1989**, is available from the U.S. Geological Survey (USGS), Books and Open-File Reports Section, Box 25425, Denver CO 80225, (303) 236-7476: USGS Open-File Report 89-640A, $1.50 for paper copy, $4.50 for microfiche.

**Inside Hawaiian Volcanoes**, a 25-minute color video, illustrates techniques of monitoring Hawaiian volcanoes. The video, aimed at audiences of all ages, includes spectacular eruption footage. Subsurface features are depicted by cutaway views, models, and computer graphics. Noted volcano cinematographer Maurice Kraft produced the video in collaboration with the USGS and the Smithsonian Institution. Orders must include check or money order (U.S. funds only) made out to Smithsonian Institution. Send to Richard S. Fiske, Natural History Building 119, Smithsonian Institution, Washington DC 20560, (202) 357-1384: videotape, VHS format $20, PAL format $25.

The teacher's guide for **Inside Hawaiian Volcanoes** contains questions and lab exercises. Order from the USGS (address above): USGS Open-file Report 89-685, $3.50 for paper copy, $4 for microfiche.

**Oceanography for Landlocked Classrooms**, for teachers of grades 7-12, contains easy-to-follow lessons and activities written by marine educators from high schools and universities. Order from National Association of Biology Teachers, 11250 Roger Bacon Drive #19, Reston VA 22090, (703) 471-1134: $15 plus $2 postage/handling.

**Water in Your Hands**, an imaginative 16-page booklet, uses cartoon characters to help children (grades 4-6) develop awareness of water quality and management problems. The instructor's guide includes activity masters, background information, implementation suggestions, optional activities, and sources of additional information. Order from Soil and Water Conservation Society, 7515 NE Ankeny Road, Ankeny IA 50021-0764, (515) 289-2331 or (800) THE-SOIL: single copies $2, discounts on bulk orders.

*(Continued on page 118,* **Earth-science education***)*

# The man who put Oregon on the Moon: James B. Irwin

Twenty-five years ago, Oregon rocks were studied by a budding astronaut, James B. Irwin, who five years later placed one on the Moon as a personal favor and expression of warm friendship to an Oregon resident. On August 8, 1991, Irwin died at the age of 61 in Colorado.

Irwin visited Oregon when it was the scene of preparation for astronauts for their volcanic field work on the Moon. We revive that history as a tribute to Irwin and a memento to our readers.

Little is known by the general public about the role the geology of Oregon played in the lunar landing and in particular the part Irwin played in actually placing a small piece of Oregon rock on the Moon.

In the mid-1960's, Oregon was selected as the location where astronauts would get experience in working on volcanic terrain similar to what they would encounter on the Moon. The Oregon Department of Geology and Mineral Industries participated in two scientific conferences in connection with the effort, the Lunar Geological Field Conference and the Andesite Conference, and published a guidebook and transactions for each of them (Bulletins 57, 62, and 65 and Open-File Report O-66-1—all out of print now).

Volcanology and especially the "lunar" landscape of central Oregon around Bend created much excitement in those days. The Lunar Geological Field Conference, for example, drew the attention and warm welcome from then Governor Mark O. Hatfield and Bend Mayor Paul Reynolds. University of Oregon volcanologist Professor Lloyd Staples and Jack Green of the cosponsoring New York Academy of Sciences expressed their feeling of being part of space program research: "Comparison of the Earth and the Moon will lead to an understanding of the differences which exist between them. This, in turn, may provide clues to the origin and development of all planetary bodies. . . . The association of crater alignments on the flanks of calderas to the parent caldera, the shear strength of ash flows and falls, the morphology of lava tubes—are all things which deserve careful analysis before manned landing on the Moon."

The feeling is reflected also in the words of then State Geologist Hollis M. Dole describing "the potential of the area, both as an outdoor laboratory for the study of volcanics and as a site for some of the research prerequisite to the establishment of a manned base station on the Moon."

Finally, we reprint here a story by the late Phil F. Brogan from the Bend Bulletin of October 2, 1971, as it was published in DOGAMI's *Ore Bin* of November 1971. We regret that we cannot reprint also the picture of the rock on the surface of the Moon with Jim Irwin's dedication and signature:

***Central Oregon rock rests on the Moon***

*There is a bit of rock from central Oregon on the bright Moon these nights as the orb circles the Earth. It was placed there by NASA Astronaut James B. Irwin who, with David R. Scott and Alfred M. Worden, was aboard Apollo 15 on the highly successful mission this past summer.*

*The story of how the Oregon rock, a splinter from a chunk of dacite near Devil's Lake on the Cascade Lakes Highway west of Bend, found an eternal resting place on the Moon starts with a dinner honoring the 16 astronauts who were guests of Bend in 1966.*

*Various Bend residents were hosts to the astronauts at a welcoming party at the Bend Golf Club. Floyd E. Watson, Bend building inspector, was host to Irwin and during the evening got well acquainted with him.*

*In time, Watson forgot the astronauts' dinner. Then in July 1971, in the list of astronauts for the Apollo 15 mission to the Moon was Irwin, graduate of the U.S. Naval Academy and University of Michigan.*

*Watson immediately wrote to Irwin, congratulating him on his appointment to the Apollo 15 command, adding "I am sending you a small sliver of central Oregon lava which I hope you will be able to deliver to the Moon for me. I have five grandchildren who would be eternally grateful to you." One of the grandsons hopes someday to enter the space program and fly to another planet.*

*Watson little expected to hear from the busy astronaut. Then came a letter from Irwin, who had toured the base of the Apennine Mountains on the Moon, ridden with Commander Scott over rugged moonscape, driven an $8-million "moon buggy" to the brink of an awesome rill, and studied billion-year-old rocks.*

*The letter was brief: "I did carry your sliver of lava to the Moon and left it there. I took a picture of the location and will send it to you as soon as it has been properly mounted."*

*The picture, autographed by Astronaut Irwin, had an arrow pointing to a small black object on the silvery lunar dust. That object was from a tongue of lava which ages ago flowed to the edge of the Devil's Lake basin. Irwin dropped the bit of rock on the Moon on July 31, 1971.*

*The story of the Oregon rock that found its way to the Moon aboard Apollo 15 may not be at an end. The Devil's Lake area is in the Bend District of the Deschutes National Forest. Ranger Jack R. Krieger is considering marking the spot, adjacent to the highway, with a roadside sign. That sign, if approved, might read:*

*"A piece of rock from this site was placed on the Moon in July 1971 by Apollo 15 astronauts."*

*—John D. Beaulieu*
*Deputy State Geologist*

## BOOK REVIEW

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

**Volcanoes of North America, United States and Canada**, compiled and edited by Charles A. Wood and Jürgen Kienle. Cambridge University Press, 1990, ISBN 0-521-36469-8, 354 p., $70.

Wood and Kienle have accomplished a remarkable feat in persuading 81 authorities to write, especially for this volume, succinct descriptions of 262 volcanoes and volcanic fields, located in 12 western states of the U.S. and in Canada.

Author Wood explains in his introduction that the many volcanoes of Mexico, Central America, and the Caribbean, although undeniably in North America, were left out because their tectonic settings are distinctly different and their history of exploration and understanding is separate from volcano studies in the United States and Canada. He suggests a companion volume on *Volcanoes of Latin America.*

The book includes only those volcanoes that are morphologically distinct and younger than 5 million years. And while a few small volcanic fields that should be included are not, because of a nearly total lack of information, the material that is presented is enough to show that, as Wood states, "There are more volcanoes in North America than anyone would have imagined . . . Additionally, the diversity of processes that built the volcanoes includes virtually all those described in textbooks."

A volcano index includes, in italic type, the names of 458 additional volcanoes that are mentioned but not specifically described. An author index lists the contributions made by each writer.

The 8½-by-11-inch-sized pages of this hardback book allow maps and photographs to illustrate most of the descriptions. The type is large and easy to read, and most maps are well readable (a few have been reduced so much that some readers may need a magnifier). Some photographs are a little hazy, due perhaps to the use of unglossed paper.

Three successive parts of the book describe the volcanoes of Alaska, Canada, and western United States, the latter including New Mexico, Colorado, and Wyoming as the easternmost states. Each of these parts begins with a discussion of the regional volcano tectonics (in addition, Hawaii is given a separate tectonic discussion), followed by a table of contents that also serves as a sequential volcano index for that part.

The Cascade Range in Oregon contains more than 3,000 shield volcanoes and cinder cones, often as yet unstudied, many of them not even named. This situation necessitated a deviation from the usual treatment of the book in that these volcanoes are not described separately; rather their features are briefly presented in a series of regional descriptions, mainly the High Cascade areas between the major peaks.

Each description begins with a block of statistical data, usually consisting of type, geographic coordinates, elevation, dimensions, eruptive history, and composition, for example:

**NEWBERRY**
**Oregon**

**Type:** Shield
**Lat/Long:** 43.68°N, 121.25°W
**Elevation:** 2,434 m
**Relief:** ~1,100 m
**Volcano/Caldera Diameter:** ~40/5x7 km
**Eruptive History:** 0.5 Ma to ~1,300 yr BP
**Composition:** Basalt to rhyolite

Next is a more detailed narrative description varying from 500 to 2,000 words. Because the book is intended to be understood by general geologists, details of geochemistry, isotopes, tephra layers, flow morphologies, and eruption histories are generally not given. The description is followed by a very handy paragraph on "How to get there" and, finally, one or two bibliographic references that are intended to introduce the reader to the available literature.

Alaska, with 93 pages containing more than 100 descriptions (predominantly in the Aleutian Islands), has two to three times the 42 pages and 34 descriptions allotted to Oregon. Although the editors suggested that inevitably some volcanoes and fields may have been overlooked, no omissions are immediately apparent. □

## *Volcano News* to be revived

In the beginning there was *Volcano News*, an interdisciplinary forum where volcanophiles of all stripes—professional and amateur, "hard" and "soft" scientists alike—could exchange information. *Volcano News* unfortunately became extinct when editor-publisher Chuck Wood became involved in editing *Volcanoes of North America.*

Janet Cullen Tanaka, a former contributing associate editor of *Volcano News*, is planning the publication of a new interdisciplinary newsletter to cover all facets of volcano studies from geophysics to emergency management.

Persons interested in contributing articles or in subscribing, or both, are invited to contact Janet as soon as possible at PO Box 405, Issaquah, WA 98027-0405, or by phone between 10:00 a.m. and 10:00 p.m. (Pacific Time) at (206) 392-7858. □

## Job-opportunity newsletter announced

Beginning in September 1991, *Earth Science Opportunities* will offer its services to earth scientists. It is conceived as a monthly newsletter that will print current employment opportunities as well as internship, fellowship, and grant announcements free of charge. Submissions may be sent by mail, e-mail, or modem and may include graphics, if these are submitted as Macintosh PICT files.

The venture is an attempt to provide a consolidated forum for job listings in all areas related to the earth sciences, alleviating the current situation where job seekers need to search a considerable number of different publications that may or may not include announcements in their particular fields of expertise.

*Earth Science Opportunities* is offered for subscription at $24.95 for six months, $44.95 for one year, or $84.95 for two years. International rates are available on request. Subscriptions should be sent and checks made payable to Editor, Earth Science Opportunities, 2089 Rt. 9, Cape May Court House, NJ 08210. The editor can be reached at (609) 624-9337; the phone number for modem and e-mail information is (609) 624-0608. □

## USGS new style guide available

The U.S. Geological Survey (USGS) has released the seventh edition of its *Suggestions to Authors* (STA 7), a guidebook for writers, reviewers, editors, typists, and other persons helping to prepare materials for publication—originally within the USGS but by now also in many other places where geologic research is written up and published.

The 8½-by-11-inch book has 289 pages. The text is loosened up with a great many illustrations and cartoons. Paperbound copies can be purchased for $18 from USGS regional offices with over-the-counter sales, such as the Northwest Region Earth Science Information Center in Spokane, Washington (phone 509-353-2524); the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402; and Printing Office book stores. □

# MINERAL EXPLORATION ACTIVITY

## MAJOR MINERAL EXPLORATION ACTIVITY

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Baker 1990 | Baboon Creek Chemstar Lime, Inc. | T. 19 S. R. 38 E. | Lime-stone | Expl |
| Baker 1990 | Cracker Creek Mine Bourne Mining Co. | T. 8 S. R. 37 E. | Gold | Expl |
| Baker 1991 | Cave Creek Nerco Exploration | Tps. 11, 12 S. R. 42 E. | Gold | App |
| Baker 1991 | Gold Ridge Mine Golconda Resources | T. 12 S. R. 43 E. | Gold | Expl |
| Baker 1991* | Lower Granview Earth Search Sciences | T. 14 S. R. 37 E. | Gold | App |
| Baker 1992 | Pole Creek Placer Dome U.S. | T. 13 S. R. 36 E. | Gold, silver | Expl |
| Coos 1991* | Seven Devils Oreg. Resources Corp. | Tps. 2, 7 S. R. 4 W. | Gold | Expl com |
| Crook 1988 | Bear Creek Freeport McMoRan | Tps. 18, 19 S. R. 18 E. | Gold | Expl |
| Crook 1991 | Bear Creek Project Coeur Explorations | T. 18 S. R. 18 E. | Gold | Expl |
| Grant 1991* | Buffalo Mine American Amex | T. 8 S. R. 35½ E. | Gold | App |
| Grant 1991* | Canyon Mtn. Cammtex International | T. 13 S. R. 32 E. | Gold | Expl |
| Grant 1992 | Standard Mine Bear Paw Mining | T. 12 S. R. 33 E. | Gold, copper | Expl |
| Harney 1990 | Pine Creek Battle Mtn. Exploratn. | T. 20 S. R. 34 E. | Gold | Expl |
| Harney 1991* | Flagstaff Butte Noranda Exploration | Tps. 3, 9 S. R. 37 E. | Gold | App |
| Jefferson 1991 | Red Jacket Bond Gold | Tps. 9, 10 S. R. 17 E. | Gold | App |
| Josephine 1990 | Martha Property Cambiex USA | T. 33 S. R. 5 W. | Gold | Expl |
| Lake 1988 | Quartz Mountain Wavecrest Resources. | T. 37 S. R. 16 E. | Gold | Expl |
| Lake 1990 | Glass Butte Galactic Services | Tps. 23, 24 S. R. 23 E. | Gold | Expl |
| Lake 1991* | 8th Drilling Series Wavecrest Resources | T. 37 S. R. 17 E. | Gold | Expl |
| Lincoln 1991 | Iron Mtn. Quarry Oreg. St. Highw. Div. | T. 10 S. R. 11 W. | Basalt | App |
| Linn 1991* | Hogg Rock Oreg. St. Highw. Div. | T. 13 S. R. 7½ E. | Rock | App |
| Linn 1991* | Quartzville Placer Dome U.S. | T. 11 S. R. 4 E. | Gold, silver | App |
| Malheur 1988 | Grassy Mountain Atlas Precious Metals | T. 22 S. R. 44 E. | Gold | Expl, com |
| Malheur 1988 | Harper Basin Project Amer. Copper & Nickel | T. 21 S. R. 42 E. | Gold | Expl |
| Malheur 1988 | Jessie Page Chevron Resources | T. 25 S. R. 43 E. | Gold | Expl |
| Malheur 1988 | Kerby Malheur Mining | T. 15 S. R. 45 E. | Gold | Expl, com |
| Malheur 1989 | Hope Butte Chevron Resources | T. 17 S. R. 43 E. | Gold | Expl, com |

## MAJOR MINERAL EXPLORATION ACTIVITY (continued)

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Malheur 1990 | Ali/Alk Atlas Precious Metals | T. 17 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Buck Gulch Teague Mineral Prod. | T. 23 S. R. 46 E. | Ben-tonite | Expl |
| Malheur 1990 | Calavera NERCO Exploration | T. 21 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Cow Valley Butte Cambiex USA, Inc. | T. 14 S. R. 40 E. | Gold | Expl |
| Malheur 1990 | Freezeout Western Mining Corp. | T. 23 S. R. 42 E. | Gold | Expl |
| Malheur 1990 | Goldfinger Site Noranda Exploration | T. 25 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Grassy Mtn. Regional Atlas Precious Metals | T. 22 S. R. 44 E. | Gold | Expl |
| Malheur 1990 | Katey Claims Asarco, Inc. | Tps. 24, 25 S. Rs. 44, 46 E. | Gold | Expl |
| Malheur 1990 | KRB Placer Dome U.S. | T. 25 S. R. 43 E. | Gold | App |
| Malheur 1990 | Lava Project Battle Mtn. Exploratn. | T. 29 S. R. 45 E. | Gold | Expl |
| Malheur 1990 | Mahogany Project Chevron Resources | T. 26 S. R. 46 E. | Gold | App |
| Malheur 1990 | Racey Project Billiton Minerals USA | T. 13 S. R. 41 E. | Gold | Expl |
| Malheur 1990 | Sand Hollow Noranda Exploration | T. 24 S. R. 43 E. | Gold | Expl |
| Malheur 1990 | Stockade Mountain BHP-Utah Internatl. | T. 26 S. Rs. 38, 39 E. | Gold | Expl |
| Malheur 1990 | Stockade Project Phelps Dodge Mining | Tps. 25, 26 S. R. 38 E. | Gold | Expl |
| Malheur 1991* | Bannock Atlas Precious Metals | T. 25 S. R. 45 E. | Gold | App |
| Malheur 1991 | Big Red Ron Johnson | T. 20 S. R. 44 E. | Gold | Expl |
| Malheur 1991* | Birch Creek Ronald Willden | T. 15 S. R. 44 E. | Gold | App |
| Malheur 1991* | Deer Butte Atlas Precious Metals | T. 21 S. R. 45 E. | Gold | App |
| Malheur 1991* | Harper Basin Atlas Precious Metals | T. 21 S. R. 42 E. | Gold | App |
| Malheur 1991 | Lucky G Sunshine Prec. Metals | T. 22 S. R. 44 E. | Gold | App |
| Malheur 1991 | Rhinehardt Site Atlas Precious Metals | Tps. 18, 19 S. R. 45 E. | Gold | Expl |
| Malheur 1991 | Sagebrush Gulch Kennecott Exploration | Tps. 21, 22 S. R. 44 | Gold | App |
| Malheur 1991 | Silver Claims Sunshine Prec. Metals | T. 23 S. R. 43 E. | Gold | App |
| Malheur 1991 | White Mountain D.E. White Mtn. Mining | T. 18 S. R. 41 E. | Dia-toms | App |
| Marion 1990 | Bornite Project Plexus Resources | T. 8 S. R. 3 E. | Copper | App com |

Explanations: App=application being processed. Expl=Exploration permit issued. Veg=Vegetation permit. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. *=New site

**Status changes**

During July, Oregon Resources Corporation joined the list of companies for which an interagency coordinating committee is appropriate. As yet, no meeting of the new committee has been scheduled. Due to a decrease in activity, the coordinating committee for Chevron's Hope Butte Project was disbanded.

**Regulatory issues**

Numerous bills relating to mining were introduced during the legislative session. House Bill (HB) 2244, significantly modified by the Governor's Mine Work Group, a multi-interest-based committee, passed unanimously out of the House Agriculture, Forestry, and Natural Resources subcommittee, was passed by the Legislature, and has become law by the Governor's signature.

Hearings have been held by the Department of Environmental Quality on its proposed water quality regulations for large-scale mining operations. Comments made during the hearings will be reviewed, before the rules are presented to the Environmental Quality Commission for adoption.

Questions or comments should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office of the Oregon Department of Geology and Mineral Industries, 1534 Queen Avenue SE, Albany, OR 97321, telephone (503) 967-2039. □

# Governor signs landmark mining bill

At a ceremony held July 31, 1991, in her office in Salem, Governor Barbara Roberts signed into law HB 2244, regulating chemical heap-leach gold mining in Oregon.

"This is a tough, practical piece of legislation," the Governor said. "We've worked hard on this. It's a solid bill that will demand adherence to strict environmental standards while establishing a fair, workable process for industry to develop this mineral resource."

A mining work group convened by the Governor's Office devoted long hours to the bill throughout the recently completed legislative session to hammer out a compromise acceptable to both environmentalists and industry. The group was chaired by the Governor's senior policy advisor for natural resources, Martha Pagel, and included representatives of both groups as well as state agencies.

HB 2244 creates a comprehensive application process for companies seeking to develop heap-leach mining operations, under the guidance of the Oregon Department of Geology and Mineral Industries (DOGAMI). Such operations have been proposed in eastern Oregon. The legislation requires that any chemical-process mining operations use "the best available, practicable, and necessary technology" to meet tough environmental requirements. It stipulates that there be no net loss of habitat value for fish and wildlife and requires reclamation of the site after development to protect human health and safety as well as wildlife. The bill also requires a complete environmental assessment of every project, as well as a thorough socio-economic assessment.

The legislation provides extensive opportunities for public input and information throughout the application process and sets a procedure for administrative and judicial review.

"I'm proud of this bill," Governor Roberts said. "This has been an important priority for me, and I congratulate the members of the legislature as well as the industry and environmental groups who have proven by this that we can work together to solve tough environmental problems while allowing responsible development of our natural resources."

*—Governor's Office news release*

# New mining law to be implemented

House Bill (HB) 2244, recently passed by the 1991 session of the Oregon Legislature and signed by Governor Barbara Roberts, provides for major changes in the regulation of chemical-process mine operations, specifically those operations that use the cyanide processing methods.

The bill was a consensus bill on many points. The consensus was built in the Governor's Mine Work Group chaired by Martha Pagel. The group consisted of representatives of state agencies, legislators, legislative committee staff, environmental groups, and industry. It is safe to say that no group was entirely satisfied with the outcome, but all left the "table" believing they could live with HB 2244.

Key provisions of the bill include (1) a site-specific environmental evaluation including a cumulative impact analysis; (2) a socioeconomic analysis for use by local communities; (3) several public input opportunities during the state permitting process; (4) backfill analysis on a case-by-case basis; (5) stringent wildlife protection and mitigation provisions; (6) a project-specific coordination group that will meet in the local area; (7) establishment of an interagency, interdisciplinary technical review team; (8) a consolidated application; (9) a consolidated public hearing on draft permits and contested cases if needed; and (10) a new judicial review procedure designed specifically for this process.

Copies of the bill may be obtained from the Bill Center located in the State Capitol Building in Salem (503-378-8551).

The bill also requires the Oregon Department of Geology and Mineral Industries (DOGAMI) to complete rules for procedural aspects by September 30, 1991. Draft rules were made available to interested parties by August 23, 1991.

Hearings were held September 9, 1991, in Ontario, Malheur County, and September 10, 1991, in Portland.

Those wishing a personal copy of the draft rules should contact the Albany office at (503) 967-2039. Costs associated with mailing such copies will be passed on to the recipients. Copies will also be accessible for review at the following public libraries:

Salem Public Library
585 Liberty Street SE
Salem, OR 97309-5010

Eugene Public Library
100 West 13th Avenue
Eugene, OR 97401-3484

Jackson County Library
413 W. Mail Street
Medford, OR 97501-2730

Lake County Library
513 Center Street
Lakeview, OR 97630-1582

Deschutes County Library
507 NW Wall Street
Bend, OR 97701-2698

Harney County Library
80 West "D"
Burns, OR 97720-1299

Malheur County Library
388 SW 2nd Avenue
Ontario, OR 97914-2712

Emma Humphrey Library
150 A Street E.
Vale, OR 97918-1345

In addition, HB 2244 rules are available for review at all DOGAMI offices. See addresses listed in the box on page 98 of this issue of *Oregon Geology*. □

## Brooks retires

Howard C. Brooks, Resident Geologist in the Baker City Field Office of the Oregon Department of Geology and Mineral Industries, has entered his well-earned retirement.

Brooks served DOGAMI at the field office for 35 years and in the process has become a venerable authority on Oregon geology, especially in Oregon's northeast.

Photo courtesy Jeff Durham, Oregon Trail Electric Coop, Baker City

*Howard C. Brooks*

Brooks has shared the results of his work by authoring or co-authoring nearly two publications—reports, books, maps, articles—for every year in office. These include comprehensive studies of gold and silver, quicksilver, and limestone in all of Oregon and were brought to a certain summation in his co-authorship and co-editorship of two books, published by the U.S. Geological Survey, on the geology of the Blue Mountains region. And he plans to continue to publish and contribute to publications.

A native of Idaho, Brooks received his geologic education at Idaho State College (B.S. 1953) and the Mackay School of Mines in Reno, Nevada (M.S. 1956). Before joining DOGAMI, he worked for Westvaco Mineral Development Department, Division of FMC Corp., and in the Nevada Mining Analytical Laboratory.

Brooks enjoys the unusual distinction of having served as member of the U.S. Bureau of Land Management Advisory Board for the Burns district. He also served the Northwest Mining Association as Trustee. In Baker City, he served on the City Council and is currently member of the Baker County Planning Commission and works with the Oregon Trail Interpretative Center and the Oregon Trail Regional Museum. He is also serving on the Baker City Golf Board and, if he has any time left, will certainly continue polishing his already fairly polished golf game. □

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***(Earth-science education,** continued from page 114)*

The USGS also offers **Make Your Own Paper Model of a Volcano**, the pattern for a three-dimensional paper model of a volcano with a cutaway look at its insides. It was designed by USGS cartographer Tau Rho Alpha of Menlo Park and is accompanied by explanatory text by Menlo Park education officer Leslie C. Gordon.

The components of the paper model of the volcano come as a two-sheet report on heavy paper. The pattern and instructions on how to cut and paste them to make the 5x2x2¾-inch model are on one sheet. The "Educator's Guide" on the other sheet includes a brief description of volcano types, questions for further study, vocabulary, and a list of suggested reading.

The model is USGS Open-File Report 91-115A and available for $1.50 (paper) or $4 (microfiche) from the USGS at the address mentioned above (see "How to Construct . . .," page 113).

The report is available also on a 3.5-inch diskette that can be used in Macintosh computers to see an animated eruption, to change patterns on the model, and to print out copies of the model on paper (Open-File Report 91-115B, $10). □

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***(Gall—Appendix,** continued from page 112)*

**APPENDIX: List and description of samples studied**

**GMC 1**: Location: Junction of Hwys. 62 and 230. Sample taken from the Mount Mazama ash flow and associated with pumice fragments, ash, and rounded pebbles. Abundant pieces of small (<3 cm in diameter) carbonized wood.

**GMC 2**: Location: Hwy. 138 at Clearwater Falls Campground turnoff. Sample taken from the Mount Mazama ash flow, and associated with pumice fragments and ash. Rootlets from the surface grow within the fragments of carbonized wood.

**GMC 3**: Location: Milepost 73, Hwy. 138 at Lake Creek, north side of road. Sample from the Mount Mazama ash flow; ample rock fragments within deposit. Sample of carbonized wood from a carbonized log.

**GMC 4**: Location: Milepost 73, Hwy. 138 at Lake Creek, south side of road. Sample from the Mount Mazama ash flow; scarcity of pumice and rock fragments; all pebbles appear to be of basaltic composition. No indication of layering or laminations.

**GMC 5**: Location: Hwy. 230, 4 mi north of junction with Hwy. 62, west side of road. Sample taken from the Mount Mazama ash flow; large pumice fragments up to 10 cm in diameter with distinctive pink-tan color of the ash flow; no bedding or laminations apparent. Outcrop located at the top of a rise, away from stream drainages.

**GMC 6**: Location: Hwy. 230, 1.3 mi north of junction with Hwy. 62, near Bybee Creek. Sample of carbonized wood from the Mount Mazama ash flow.

**GMC 7**: Location: Hwy. 230, 0.1 mi north of junction with Hwy. 62. Sample taken from the Mount Mazama ash flow, and composed of a carbonized log with growth rings still evident.

**GHC 1**: Location: Interstate 5 road cut, 0.5 mi north of Mount Ashland exit, southbound lane. Sample from the Upper Cretaceous Hornbrook Formation, from a nearshore marine mudstone. Carbonized pieces composed of very small (<3cm in diameter), friable, homogeneous fragments.

**GHC 2**: Location: Interstate 5 road cut, 0.5 mi north of Mount Ashland exit, southbound lane. Sample from the Upper Cretaceous Hornbrook Formation, from a nearshore marine mudstone. Sample of carbonized wood, with growth rings indistinct, found within a concretion; the sample appears to be partially silicified.

**GCC 1**: Location: Junction of Colestin Road and Mount Ashland access road. Sample of lapilli-sized, planar, carbonized wood from the Colestin Formation, from a bed mapped by Bestland (1985) as a white, crystal ash-flow tuff (informal member Tct).

**GCC 2**: Location: Interstate 5, 2.7 mi north of California border, northbound lane, benched road cut. Sample from the Colestin Formation, from a 5-ft-thick welded tuff containing carbonized logs and flattened pumice fragments. The logs are partially silicified and show indistinct growth rings.

**GCC 3**: Location: Interstate 5, northbound lane at Siskiyou Pass summit road cut. Sample taken from Bestland's (1985) informal Tct member of the Colestin Formation, from a partially silicified carbonized log. Growth rings are distinct in the sample.

**GSC 1-3**: Location: Abandoned Shale City pit, accessed from Dead Indian Hwy., east of Ashland. Samples taken from a finely laminated lacustrine deposit, composed of volcanic ash with interbedded, more resistant, carbon-rich beds. Samples consist of a glossy, homogeneous, highly cleaved carbon, occurring in thin bands and isolated fragments.

**GU 1**: Location: Rock Mesa, near South Sister, Deschutes County, Oregon. Sample obtained from the U.S.Geological Survey, Vancouver, Washington. Sample from carbonized log found in growth position and buried by 2.25 m of hot air-fall tephra. Sample site located near the volcanic vent, attested to by the coarseness of the fragments comprising the deposit.

**H87-15A1-2**: Windy Ridge, northeast of Mount St. Helens. Sample taken from the Mount St. Helens blast deposit. The blast deposit is composed of loose, friable, juvenile, and accidental material.

**GFC 1-3**: Location: Ashland, Oregon, recent forest-fire burn areas; all three samples taken from charred logs.

**GS 1 (= SIL 1):** Comparison sample of silicified wood for study of silification.

**GRW 1**: Comparison sample of raw wood, not silicified or carbonized, for examination of undamaged middle lamellae. □

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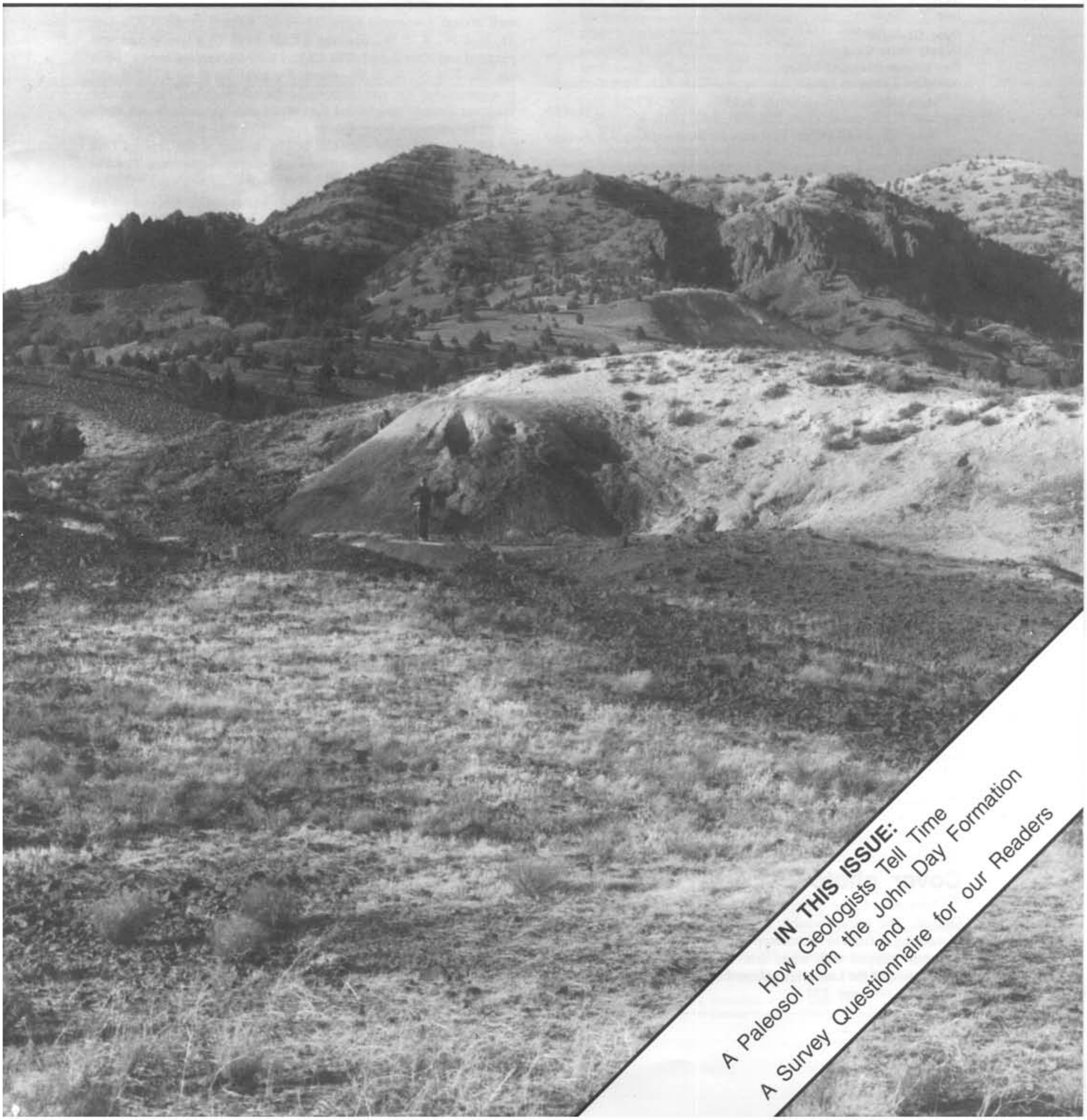

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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department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

## Cover photo

Area near Camp Hancock in Wheeler County, central Oregon. The person visible near the center of the photo is standing in front of an outcrop of red John Day Formation claystone capped with white ash. This prominent knoll is the location of the Luca clay paleosol described in the article beginning on page 131.

## OIL AND GAS NEWS

### Drilling activity at Mist Gas Field

Drilling activity continues at the Mist Gas Field, Columbia County. Nahama and Weagant Energy continued the multi-well drilling program that began during July. The Columbia County 34-31-65, located in the SE¼ sec. 31, T. 6 N., R. 5 W., reached a total depth of 2,064 ft, was plugged and redrilled to a depth of 1,902 ft, and is now a successful gas completion. The next well drilled, Longview Fibre 22-31-65, located in the NW¼ sec. 31, T. 6 N., R. 5 W., reached a total depth of 1,991 ft and was plugged and abandoned. The CER 14-26-64, located in the SW¼ sec 26, T. 6 N., R. 4 W., reached a total depth of 2,702 ft and is a successful gas completion. So far for the year, Nahama and Weagant Energy has drilled five wells and one redrill, and three of these attempts have led to successful gas completions.

Northwest Natural Gas Co. began drilling at the Natural Gas Storage Project at the Mist Gas Field during September. The IW 13b-11 is a gas injection-withdrawal service well being drilled in the Bruer Pool. Upon completion of this well, drilling of an injection-withdrawal service well, IW 23d-3, is planned for the Flora Pool.

### Seismic surveys conducted in Oregon

Two seismic surveys were completed in Oregon during September and October. The first was by Cimmaron Land Services, which conducted a wide-range refraction/reflection seismic survey in Wasco, Jefferson, and Wheeler Counties. The survey is located in the western Columbia River Basin and intended to define areas with stratigraphic and structural conditions necessary for potential oil and gas accumulations. The U.S. Geological Survey conducted a seismic refraction survey in western Oregon with the intent of helping scientists assess earthquake hazards in the Pacific Northwest more accurately. This seismic survey is a portion of a total project that extends north from western Oregon through Washington into southern British Columbia, Canada.

### NWPA Kyle Huber luncheon scheduled

The annual Kyle Huber luncheon will be held by the Northwest Petroleum Association (NWPA) on November 8. At this luncheon, the Kyle Huber Award will be presented to the individual or company that has been selected to have made the most significant contribution to energy resource development in the Pacific Northwest during the year. Paul Dudley, independent geologist from Bend, will be the speaker. Details on the luncheon can be obtained from Shelley at (503) 220-2573.

### Recent permits

| Permit no. | Operator, well, API number | Location | Status, proposed total depth (ft) |
|---|---|---|---|
| 468 | Nahama and Weagant<br>CER 24-22-64<br>36-009-00293 | SW¼ sec. 22<br>T. 6 N., R. 4 W.<br>Columbia County | Permit;<br>2,600. |

□

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# How geologists tell time

by Evelyn M. VandenDolder, Editor, Arizona Geological Survey. 

The following article was originally published as a two-part article in the winter 1990 (v. 20, no. 4) and spring 1991 (v. 21, no. 1) issues of *Arizona Geology*, published by the Arizona Geological Survey, 845 N. Park Avenue, Suite 100, Tucson, AZ 85719. With the publisher's permission, Part 1 is reprinted here, and Part 2 will appear in the next issue of *Oregon Geology*. In a few cases, the original illustrations had to be replaced with other, similar illustrations. —*Editors*

## Part 1: Introduction and relative dating techniques

### INTRODUCTION

The Shroud of Turin, revered for centuries as the burial garment of Christ, retains the imprint of a man who was apparently scourged and crucified. The first recorded exhibit of the shroud was at Lirey, France, in the 1350's. After passing through many hands and cities, it was ultimately enshrined in 1694 in the Royal Chapel of Turin Cathedral (Damon and others, 1989).

In the spring of 1988, as requested by the Vatican, owner of the shroud, radiocarbon laboratories in Oxford, England; Zurich, Switzerland; and Tucson, Arizona (Laboratory of Isotope Geochemistry, University of Arizona) dated the shroud by accelerator mass spectrometry. Each of the three laboratories dated four samples: one 50-milligram whole-cloth sample from the shroud and three control samples from other fabrics, the ages of which were known from previous radiocarbon measurements or from historical evidence. The age of the shroud was determined to be A.D. 1260-1390, with at least 95-percent confidence. The shroud, therefore, is medieval (Damon and others, 1989).

Radiocarbon dating has been widely used to date cultural artifacts, such as the Shroud of Turin and charcoal from late Pleistocene (11,000-year-old) fires built by early hunters in southeastern Arizona (Haynes, 1987). The radiocarbon technique has also been used to date ground water in the Tucson basin to determine its recharge rate. Because it has been popularized by the media in stories of archaeological discoveries, the radiocarbon method is the best known dating technique. It is, however, only one of many methods that scientists use to date objects (Figure 1). Other techniques that are also based on the rates of radioactive decay allow geologists to date rocks that are millions or even billions, not just thousands, of years old.

This paper, the first section of a two-part article, gives an abbreviated history of dating rocks and minerals, describes the geologic time scale, and summarizes several relative dating techniques. Part 2 of the article focuses on absolute dating techniques based on tree rings, varve sequences, and radioactive decay. Used together, relative and absolute dating methods en-

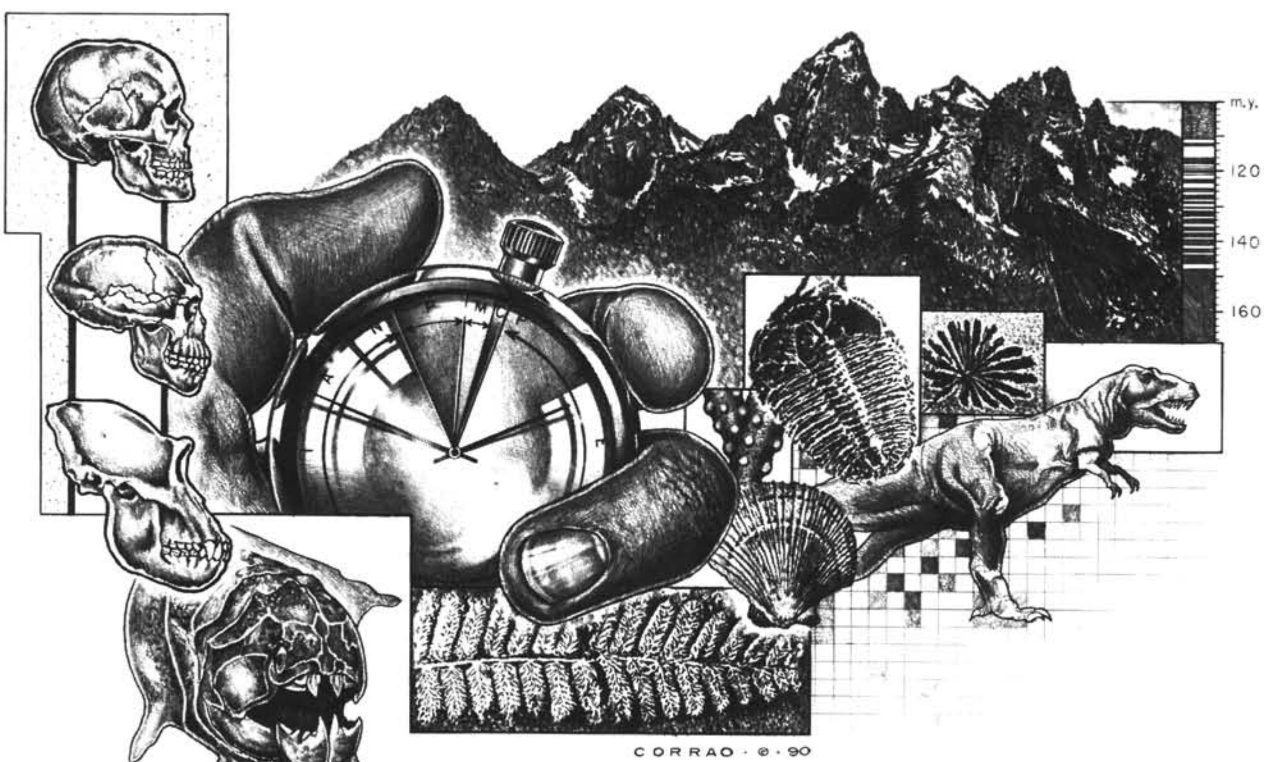


*Figure 1. Today's geologists rely on several relative and absolute dating techniques, such as those based on fossils, paleomagnetism, and radioactive decay, to determine the ages of rocks and the order of geologic events. Drawing by Peter F. Corrao, Arizona Geological Survey.*

able geologists to date fossils and rock formations and to establish a "calendar" of past geologic events.

## HISTORY OF DATING

One of the most important contributions to modern scientific thought is the concept of geologic time. Humans have pondered the age of the Earth and the rocks that compose it for thousands of years. Eastern and western cultures, however, have held very different concepts of time. The Hindus, for example, view time as cyclical, a continuing process of birth, life, death, and rebirth, whereas Judeo-Christian cultures generally conceptualize time as linear, with a beginning and an end. Ancient Hindu philosophers believed that one cycle of the universe equaled one day in the life of Brahma, the creator god, or approximately 4.3 billion years (b.y.). Hindu scriptures postulated that the Earth was almost halfway through one cycle, or 2 b.y. old (Sawkins and others, 1978). This ancient estimate is amazingly close to the actual age of the Earth.

The science of geology, however, evolved in the western world, as did the concept of geologic time. Some ancient Greeks deduced (from observation) that geologic processes took considerable amounts of time. Xenophanes of Colophon (570-470 B.C.) was the first of the early Greek philosophers to recognize the antiquity of both fossils and sedimentary rocks. Around 450 B.C., Herodotus, the Greek historian, concluded that the Nile delta was built from the deposits left by countless floods and thus took thousands of years to form. Other Greek and Roman philosophers, such as Aristotle, and early Christian scholars, such as St. Augustine, continued to explain natural phenomena through deductive reasoning (Press and Siever, 1982).

Despite the insight of these early thinkers, for several centuries the concept of geologic time remained as constricted as the western notion of linear time. During the late Middle Ages, theology permeated scientific thought in Europe. The age of the Earth was determined by only one "proof": the book of Genesis. In the mid-1660's, Archbishop James Usher of Ireland and Dr. John Lightfoot, a Biblical scholar from Cambridge, England, concluded from scriptural analysis that the Earth was created at 9:00 a.m. on October 26, 4004 B.C. (Stokes, 1966; Press and Siever, 1982). Literal interpretation of the Bible was so common that many Christians, including scientists, believed that date, which was printed as an explanatory note in several editions of the Bible (Stokes, 1966). Before 1750, most scientists believed that all sedimentary rocks were deposited during the Great Flood of Noah's time. Other surface features, such as mountains, were believed to be the result of intermittent catastrophes (Faure, 1977). Until the late 18th century, most scientists did not question the orthodox tenets advocated by religious scholars to explain the age and origin of the Earth.

During the 18th and 19th centuries, scientific observations on depositional rates of sediments and the salinity of oceans gradually increased age estimates of the Earth to 100 million years (m.y.; Stokes, 1966; Press and Siever, 1982). In 1859, Charles Darwin published his magnum opus, *On the Origin of Species by Means of Natural Selection.* As the theory of evolution became more widely accepted, fossils were used to calibrate a stratigraphic time scale. Scientists made reasonable chronological assessments based on evolutionary theory; Darwin estimated that it had taken 300 m.y. for complex life to evolve. Increasing estimates of the Earth's age, however, ousted the human species from its egocentric position in the universe. Geologists were opposed, as were astronomers and evolutionary biologists before them, by religious believers who viewed scientific theories as antithetical to Biblical teachings.

While geologists and biologists were extending estimates of the Earth's age, physicists were lowering them. In the mid-18th century, Comte de Buffon of France calculated the age of the Earth based on the assumption that the Earth was solid and had cooled from a molten state. Because he believed that the Earth's interior was iron, Buffon used his measurements on the melting and cooling rates of iron balls to calculate how long it took the molten Earth to cool to its present temperature. He estimated that the Earth was 75,000 years old (Press and Siever, 1982).

In 1854, Herman von Helmholtz, a physicist who helped to establish the science of thermodynamics, theorized about the source of the Sun's light. He believed that it was created by gravitational contraction of the Sun's mass. Particles presumably fell into the center of the Sun, releasing energy in the forms of heat and light. Helmholtz estimated that the Sun began to collapse 20 to 40 m.y. ago (Press and Siever, 1982).

Late in the 19th century, William Thompson (Lord Kelvin), the British mathematician and physicist, applied Buffon's estimates of the Earth's cooling rate to Helmholtz's theories on the Sun's luminosity. Kelvin believed that the Sun was also cooling off and that the Earth would have been too hot to support life before the Sun began to collapse (Sawkins and others, 1978; Press and Siever, 1982). His estimate of the Earth's age (20 to 40 m.y.) was reasonable, based on the sources of energy known at that time. It did not, however, account for the internal heat of the Earth and Sun generated by radioactive decay. Kelvin's estimate caused a regression in scientists' understanding of geologic time. Not until the discovery of radioactivity, the energy within particles of matter, did estimates even approach the age of the Earth.

In the 1890's, three physicists made discoveries that dramatically changed the way scientists viewed the natural world: Antoine Henri Becquerel discovered radioactivity in uranium, Wilhelm Roentgen discovered X-rays, and Marie Sklodowska Curie discovered the radioactive element radium (Press and Siever, 1982). The British physicist Ernest Rutherford was the first to suggest that radioactive minerals could be used to date rocks. He, in fact, dated a uranium mineral in his laboratory in 1906. In that same year, B.B. Boltwood, an American chemist, discovered "ionium," an isotope of thorium; in 1907, he published a list of geologic ages based on radioactivity (Press and Siever, 1982; Newman, 1988). During the following decades, scientists determined the full series of decay products created by natural radioactive disintegration. Using a scientific instrument called a mass spectrometer, scientists were able to refine radiometric dating and establish that the Earth was not millions, but billions of years old. The oldest dated rocks on Earth are almost 4 b.y. old. The Earth, however, is estimated to be more than 4.5 b.y. old, based on the radiometric ages of meteorites and lunar rocks that are thought to record the age of the solar system, including the Earth (Newman, 1988). The earliest life forms preserved in the Earth's rock record (bacteria and blue-green algae) are about 3.5 b.y. old (Lambert and the Diagram Group, 1988).

## GEOLOGIC TIME SCALE

### Relative vs. absolute

**Geochronology**, the study and measurement of time as it relates to the history of the Earth, is based on two scales, relative and absolute. **Relative time scales**, defined by sedimentary rock sequences and their included fossils, arrange events in order of occurrence. A geologic event or rock unit is identified as being relatively younger or older than other events or units. **Absolute time scales**, measured in years before the present (B.P.; "present" is defined as A.D. 1950), give more definitive dates for events or units.* Absolute time, most commonly determined by radioactive decay of elements, is by no means "absolute": The precision and accuracy of dating techniques continue to be perfected (Duffield, 1990).

* Geologists use several abbreviations for units of geologic time. For example, "40 million years ago" might be written as "40 m.y. ago," "40 m.y.B.P.," or "40 Ma" (for "Mega-annum"). Similarly, "2 billion years ago" could be abbreviated as "2 b.y. ago," "2 b.y.B.P.," or "2 Ga" (for "Giga-annum"). Some geologists also abbreviate thousands of years as "ka" (for "kilo-annum"); e.g., "30,000 years" could be written as "30 ka."

There are advantages and disadvantages to each time scale. The relative scale based on fossils, used to chronologize the last 570 m.y. of Earth history, is a powerful and accurate method for correlating sedimentary rocks, but cannot be used by itself to assign ages in years. The absolute scale based on radiometric dating can provide dates for igneous and metamorphic rocks, but the date may not represent the true age of the rock if it has a complex thermal history. The two scales are, in fact, complementary: The relative scale determines the positional relationships among rock units; the absolute scale calibrates the relative scale. Generally, fossiliferous sedimentary rocks are dated by relative methods, and nonfossiliferous igneous and metamorphic rocks are dated by absolute techniques. Most sedimentary rocks cannot be dated radiometrically because the mineral grains within the sediments have typically been derived from the weathering of much older rocks and transported to the depositional site. The fossils, however, formed at about the same time as sedimentation. In 1913, the British geologist Arthur Holmes published *The Age of the Earth*, in which he plotted the ages of fossil-bearing sedimentary rocks against radiometrically dated ages of igneous rocks that crosscut them. He was the first to synchronize the relative and absolute time scales (Press and Siever, 1982).

### From eons to ages

Geologists divide geologic time into the following main units, each of which is a smaller subdivision of time than the previous unit: eons, eras, periods, epochs, and ages (Figure 2).

Each of the three eons that encompass all of Earth history is a broad span of time distinguished by the general character of life that existed then. The Archean ("ancient") Eon, the earliest eon, is also the longest and least understood. During that time, the first microcontinents formed and primitive life forms appeared. ("Pre-Archean time" is an informal term without a specific rank that applies to the interval between the origin of the Earth and the formation of solid land masses.) The Proterozoic ("former life") Eon brought the first large continents and soft-bodied animals. These intervals, collectively known as the Precambrian, comprise more than 85 percent of geologic time and extend from the origin of the Earth more than 4.5 b.y. ago to the appearance of abundant (and well-preserved) life forms 570 m.y. ago. The Precambrian is radiometrically dated from episodes of igneous intrusion, metamorphism, and mountain building. The Phanerozoic ("visible life") Eon is the last, shortest, and best recorded eon. It is dated mainly from fossil-bearing sediments and includes the last 570 m.y. of Earth history. The Phanerozoic Eon is subdivided into the Paleozoic ("ancient life"), Mesozoic ("middle life"), and Cenozoic ("recent life") Eras (Lambert and the Diagram Group, 1988).

A period is a shorter span of time partly distinguished by evidence of major disturbances of the Earth's crust (Newman, 1988). The name of each period is derived either from the geographic locality where formations of that age were first studied or are well exposed or from a particular characteristic of those formations. The Pennsylvanian Period, for example, is named after the State of Pennsylvania, where rocks of this age are well exposed. The Cretaceous Period, named from the Latin word for "chalk" (*creta*), is named after the white chalk cliffs along the English Channel (Newman, 1988).

The names of epochs within the Cenozoic Era are based on the similarity of fossil molluscs to living molluscs. The Pleistocene Epoch, for example, is named from the Greek words *pleistos* ("most") and *kainos* ("recent") and includes rocks that contain 90- to 100-percent modern mollusc species. In contrast, the Paleocene Epoch, named from *palaios* ("ancient") and *kainos*, includes rocks that contain no modern mollusc species (Stokes, 1966). Ages within each epoch are named after geographic localities in which rocks of those ages are especially well exposed. Each unit of geologic time, from eons to ages, may also be partitioned into subunits through the use of the prefixes "early," "middle," and "late."

| EON | ERA | PERIOD | | EPOCH | AGE (m.y. ago) |
|---|---|---|---|---|---|
| Phanerozoic | Cenozoic | Quaternary | | Holocene | |
| | | | | Pleistocene | 0.01 |
| | | Tertiary | Neogene | Pliocene | 1.6 |
| | | | | Miocene | 5.3 |
| | | | Paleogene | Oligocene | 23.7 |
| | | | | Eocene | 36.6 |
| | | | | Paleocene | 57.8 |
| | Mesozoic | Cretaceous | | Late | 66.4 |
| | | | | Early | |
| | | Jurassic | | Late | 144 |
| | | | | Middle | |
| | | | | Early | |
| | | Triassic | | Late | 208 |
| | | | | Middle | |
| | | | | Early | |
| | Paleozoic | Permian | | Late | 245 |
| | | | | Early | |
| | | Carboniferous | Pennsylvanian | Late | 286 |
| | | | Mississippian | Early | 320 |
| | | Devonian | | Late | 360 |
| | | | | Middle | |
| | | | | Early | |
| | | Silurian | | Late | 408 |
| | | | | Early | |
| | | Ordovician | | Late | 438 |
| | | | | Middle | |
| | | | | Early | |
| | | Cambrian | | Late | 505 |
| | | | | Middle | |
| | | | | Early | |
| Precambrian: Proterozoic | Late | | | | 570 |
| | Middle | | | | 900 |
| | Early | | | | 1600 |
| Precambrian: Archean | Late | | | | 2500 |
| | Middle | | | | 3000 |
| | Early | | | | 3400 |
| Precambrian | pre-Archean | | | | 3800? |
| | | | | | 4550 |

*Figure 2. Geologic time scale. Age estimates of time boundaries are in millions of years (m.y.). Ages (subdivisions of epochs) are not shown. Sizes of time "slots" do not reflect proportionate lengths of time intervals. Rocks older than 570 m.y. are called Precambrian, a time term without specific rank. Geologic time prior to 3,800 m.y. ago is called pre-Archean, a term also without specific rank. The Mississippian and Pennsylvanian Periods, recognized in the United States, are collectively referred to as the Carboniferous Period, a term commonly used by geologists in other parts of the world. The Neogene and Paleogene are subperiods of the Tertiary Period. Modified from Palmer (1983), p. 504.*

Scientists continue to refine the geologic time scale and revise the chronology of geologic events as more sophisticated technology provides more accurate radiometric dates for rocks and minerals (e.g., Odin, 1982; Palmer, 1983).

## RELATIVE DATING TECHNIQUES

### General principles

Three fundamental laws or principles of geology form the basis for interpreting the relative sequence of geologic events in an area. The **law of uniformitarianism**, proposed by James Hutton in 1795 and popularized by John Playfair in 1802 and Charles Lyell in 1830, states that the present is the key to the past (Stokes, 1966; Poort, 1980). The physical, chemical, and biological laws of nature that govern processes today controlled identical or similar processes during the past. Interpretations of the events of geologic history, therefore, are based on analyses of modern-day analogues. Uniformitarianism, however, does not imply that the rates of these events or processes were constant over time.

The **law of original horizontality**, proffered by the Danish court physician Nicolaus Steno in 1669, states that water-laid sedimentary rocks are originally horizontal, or parallel to the Earth's surface, because the sediments that compose them were deposited in horizontal layers on the bottoms of oceans, lakes, or rivers (Press and Siever, 1982). If a sedimentary rock unit is folded or tilted, therefore, it was disturbed after it was deposited.

The **law of superposition**, also proposed by Steno in 1669 and established by Hutton about 1795, states that in any undisturbed sequence of sedimentary strata, the oldest layer is at the bottom and the youngest is at the top (Poort, 1980; Press and Siever, 1982). In other words, each layer is younger than the underlying bed on which it was deposited (Figure 3). This law assumes that the strata have not been overturned by faulting or folding.

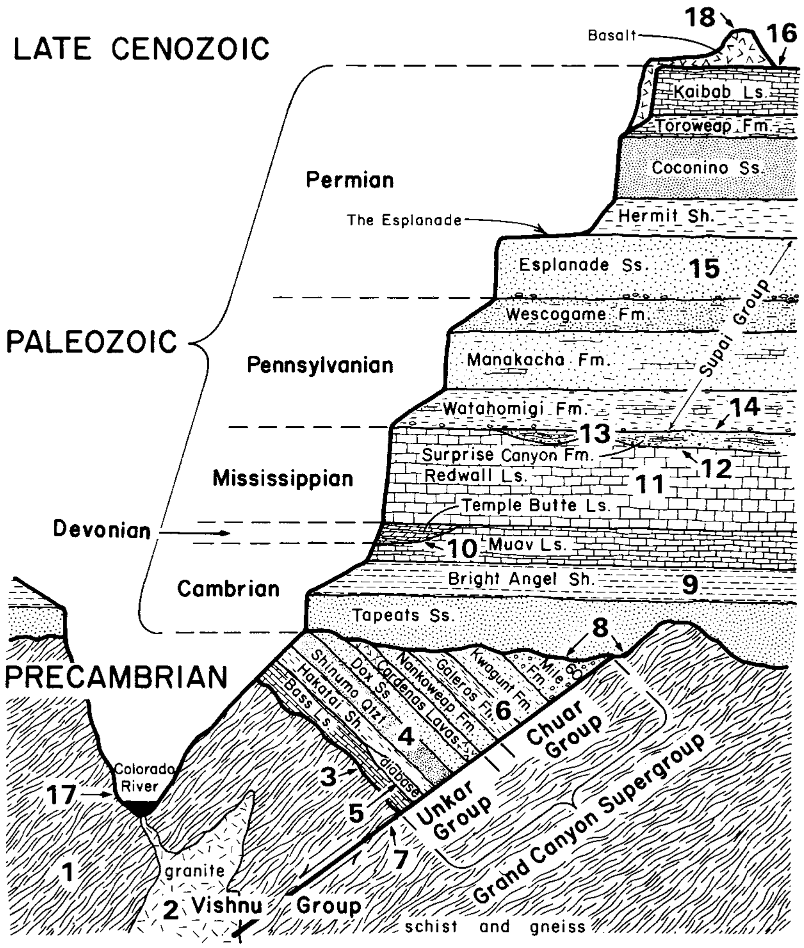


*Figure 3. Generalized stratigraphic section of rock units in the Grand Canyon, illustrating superpositional, crosscutting, and unconformable relationships. Not all unconformities have been identified. The order of major geologic events and ages of rock units, from oldest to youngest, are as follows: (1) formation and metamorphism of Vishnu Group (schist and gneiss); (2) granitic intrusion; (3) erosion and formation of nonconformity (about 450 m.y. missing); (4) deposition of Bass Limestone, Hakatai Shale, Shinumo Quartzite, and Dox Sandstone; (5) intrusion of diabase sill; (6) deposition of rest of Grand Canyon Supergroup; (7) faulting and tilting of Grand Canyon Supergroup; (8) uplift and extensive erosion; formation of angular unconformity between Grand Canyon Supergroup and Tapeats Sandstone (at least 300 m.y. missing); formation of nonconformity between Vishnu Group and Tapeats Sandstone ("The Great Unconformity"; more than 1 b.y. missing); (9) deposition of Tapeats Sandstone, Bright Angel Shale, and Muav Limestone; (10) erosion and formation of disconformity (about 135 m.y. missing); (11) deposition of Temple Butte Limestone (in channels) and Redwall Limestone; (12) erosion and formation of disconformity (a few million years missing); (13) deposition of Surprise Canyon Formation in estuaries, caves, and collapsed depressions; (14) erosion and formation of disconformity (about 15 m.y. missing); (15) deposition of Supai Group, Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone; (16) uplift and extensive erosion; all Mesozoic and nearly all Cenozoic sedimentary rocks stripped away or never deposited (about 243 m.y. missing); (17) cutting of Grand Canyon (starting about 5 m.y. ago); and (18) volcanic eruptions. Modified from Potochnik and Reynolds, 1986, p. 2.*

### Faunal succession

The British geologist William "Strata" Smith (1769-1839) determined that each layer of fossil-bearing strata within a sedimentary sequence could be distinguished from the others by the fossils contained within it (Poort, 1980). Smith proposed the **law of faunal succession**, which states that assemblages of fossil organisms (both plants and animals) preserved in rock strata succeed one another in a definite and recognizable order. Evolutionary changes and changes in fossil assemblages are preserved in successive layers of sediments. In general, the older the rock is, the greater are the differences between fossil species within the rock and living species. The fossil content of rocks may, therefore, be used to determine the relative ages of sedimentary strata and to correlate them with rock formations in other geographic areas.

Index fossils are especially useful in correlating strata. An **index fossil** is a fossil from an organism that had a distinctive appearance, was widely distributed, and lived during a relatively short interval, such as an epoch or less. Trilobites and ammonites, for example, may be used as index fossils. Other fossils, such as shark teeth, are not very useful in dating rocks because the species lived during too long an interval of geologic time. Correlating **fossil assemblages**, or groups of distinctive fossils, is the best way to date rocks because the sediments must have been deposited when all the fossil species existed.

Many species, however, have left no record because their remains have not been preserved in rock. This nonfossilization may be due to the species' lack of hardened skeletons, destruction of their hard parts by predators or waves, erosion or metamorphism of the fossilized rocks, or other factors. Scientists estimate that less than 1 percent of all species that ever lived have been identified (Sawkins and others, 1978).

### Crosscutting relationships and included fragments

Any rock unit or fault that cuts across other rock units is younger than the units it cuts (Figure 3). Crosscutting units include igneous intrusions of solidified magma. Simply stated, crosscutting relationships indicate that a disrupted pattern (a rock sequence) is older than the cause of the disruption (an igneous intrusion). Although a rock unit may not be intersected by an intrusion, it could still be identified as older than the intrusion if the unit is metamorphosed near the intrusion (i.e., if it was altered by the intrusion's heat). If fragments of one rock formation are contained within another, the former rock formation is older than the latter.

### Unconformities

An **unconformity** is a surface that represents a break or gap in the geologic record due to erosion or nondeposition. These gaps are recognized by abrupt and striking changes in the composition or orientation of the rocks and by a marked age difference between the rocks above and below the unconformity. Unconformities are commonly caused by uplift of an area, which induces erosion and removal of previously formed rock units.

Geologists classify unconformities into three types: nonconformities, angular unconformities, and disconformities. A **nonconformity** is a break between eroded igneous or metamorphic rocks and younger sedimentary strata (Figure 3). A nonconformity may be identified by the presence of an erosional surface composed of broken fragments of the underlying rock unit or by a lack of metamorphism in the strata overlying an igneous or metamorphic formation. Because intrusive igneous and metamorphic rocks form deep below the Earth's crust, a nonconformity generally indicates that deep or long-lasting erosion occurred before additional sediments were deposited (Poort, 1980).

An **angular unconformity** is an erosional surface between tilted or folded older sedimentary rocks and younger sedimentary strata that are oriented differently (Figure 3). This type of unconformity indicates that the underlying rocks were deposited, folded or tilted, uplifted, and eroded before the overlying rocks were deposited.

A **disconformity** is a surface that represents a gap between essentially parallel sedimentary strata (Figure 3). Because the strata have the same orientation and an erosional surface may not be apparent, a disconformity is the most difficult unconformity to detect. It is commonly identified by studying the fossils within the rock units and recognizing a substantial gap in the faunal succession. A disconformity implies that the area was uplifted, but not severely deformed or metamorphosed (Poort, 1980).

Because several geologic events could have taken place during these missing intervals, unconformities must be included in the reconstruction of an area's geologic history. Unconformities help geologists to determine the relative sequence, duration, and intensity of geologic processes within a particular region.

### Paleomagnetic properties

The Earth is surrounded by a magnetic field believed to originate in the fluid part of its iron core. Heat generated by radioactivity in the Earth's core stirs the fluid into convective motion. A weak magnetic field interacting with the moving iron fluid generates electric currents, creating a stronger magnetic field and a self-sustaining magnetic system (Press and Siever, 1982).

The Earth's magnetic field, like a bar magnet, has a specific direction that is defined by the magnetic north and south poles. Geomagnetic north, the direction to which a compass needle points, is not the same as geographic or true north. True north coincides with the Earth's axis of rotation; geomagnetic north is presently inclined about 11° from true north. The direction of the geomagnetic field at any point on the Earth's surface includes its **declination** (its angle east or west of true north) and its **inclination** (its angle with respect to the Earth's surface). Declination varies with both latitude and longitude. In Flagstaff, Arizona, for example, the geomagnetic north pole is 13.5° east of true north, whereas in Tucson it is 12.5° east. Inclination varies primarily with latitude. At the magnetic poles, the inclination is vertical; near the magnetic Equator, it is horizontal. The intensity of the geomagnetic field also varies with latitude; it is strong at the poles, but relatively weak at the Equator. Both the intensity and direction of the geomagnetic field vary gradually with time, a phenomenon called **secular variation**. Despite this deviation, the average position of the magnetic pole over millions of years has centered on the Earth's rotational (geographic) pole (Press and Siever, 1982).

Rocks may contain a magnetic signature that reflects the orientation of the Earth's magnetic field when the rocks were formed. This signature is recorded when iron-rich minerals crystallize from a molten state, are deposited in calm bodies of water, such as an ocean, or crystallize within a rock during metamorphism or diagenesis (the processes that compact and harden sediments and turn them into rock). When molten materials cool and harden and when sediments lithify, the magnetic iron minerals are "frozen" in place, essentially pointing to the Earth's magnetic pole like a compass needle. This **remanent magnetization** has a fixed direction that is independent of the current magnetic field of the Earth. Remanent magnetization in rocks leaves a record of the Earth's ancient magnetic field, just as a fossil leaves a record of ancient life.

**Paleomagnetism**, the study of the Earth's magnetic field during the geologic past, involves measuring both the direction and intensity of remanent magnetization in rocks. By comparing the paleomagnetic properties of rocks of similar age on different continents, scientists discovered during the 1950's and 1960's that the positions of the magnetic poles inscribed in the rocks did not agree. If, however, the continents were reassembled on the globe by matching the shapes of their edges like the pieces of a puzzle, the directions of the paleomagnetic poles also coincided. Paleomagnetism thus provided evidence of continental drift. To reconstruct the positions of the continents during the geologic past, scientists had to determine the average position of the geomagnetic pole from numerous sample sets, each of which included rocks dated within a few million years of each other. If the average geomagnetic pole and the geographic pole did not match, scientists conceptually moved the continents on the globe until the poles coincided and the previous geographic positions were established.

Paleomagnetic studies of layered sequences of lava flows on land revealed that the geomagnetic field has reversed itself every few hundred thousand years, taking a few thousand years or so to change its direction (Press and Siever, 1982). The history of magnetic reversals over the past 7 m.y. has been constructed by piecing together the ages and polarities of lava beds around the world. Based on this restoration of geomagnetic history, scientists compiled a time scale of magnetic reversals consisting of normal and reverse magnetic epochs (Figure 4). Each epoch lasted a few hundred thousand years or more, but included short-lived reversals, called **magnetic events**, that lasted from several thousand to 200,000 years (Press and Siever, 1982). The cause of geomagnetic reversals, however, is unclear.

Highly sensitive magnetometers developed during World War II to detect enemy submarines were later adapted by oceanographers to study the sea floor. These scientists discovered bands of magnetic anomalies that parallel the mid-oceanic ridges. The bands are almost perfectly symmetrical with respect to the ridge axes. In other words, bands of normal and reversed magnetism (known as positive and negative magnetic anomalies, respectively) in the rocks on one side of a ridge are mirrored in the rocks on the opposite side (Figure 5). In the 1960's, scientists suggested that these duplicate patterns were evidence for the theory of sea-floor spreading. This theory proposes that new oceanic crust solidifies from magma forced upward into the mid-oceanic ridges and spreads outward as it is pushed aside by new upwellings of magma. By comparing the magnetic anomalies on the sea floor with the magnetic reversals in lava flows on land, scientists were able to determine sea-floor spreading rates. Because the geomagnetic record is longer and more complete on the ocean floor than on land, scientists used these spreading rates. Because the geomagnetic record is longer and more complete on the ocean floor than on land, scientists

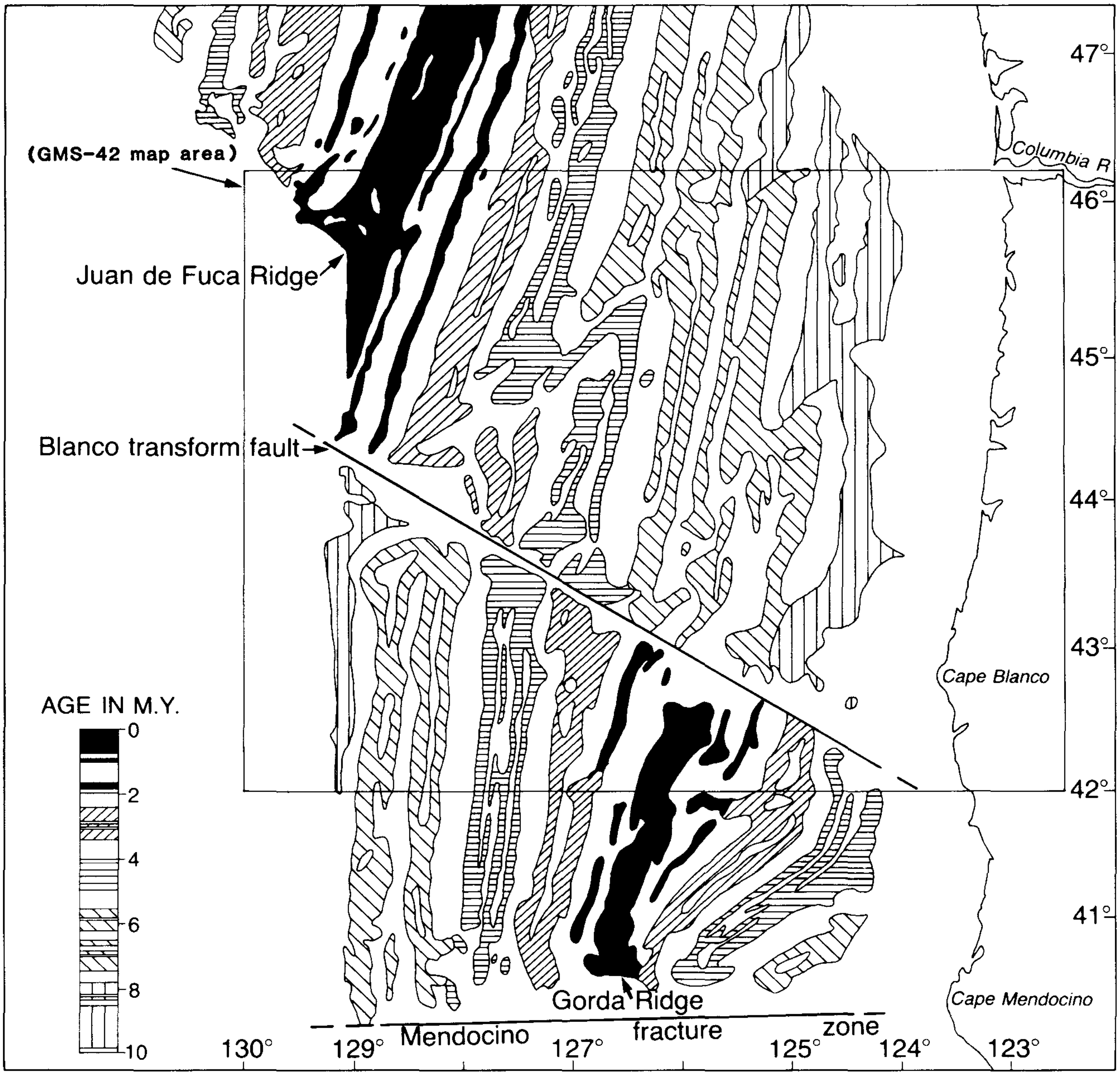


*Figure 4. Magnetic anomaly map of the Pacific Ocean floor off the coast of Washington, Oregon, and California, showing zones of rocks with normal (black and patterned bands) and reversed polarity and their ages on the geologic time scale. Note the symmetry of rock ages on both sides of the ocean ridges. Modified from Peterson and others (1986).*

used these spreading rates to extend the time scale of geomagnetic reversals back to the Jurassic Period, 162 m.y. ago (Press and Siever, 1982).

Paleomagnetism has provided not only a method to correlate rock formations but also evidence of continental drift and sea-floor spreading, two aspects of the unifying geologic theory of plate tectonics. One drawback of this method, however, is that magnetism in rocks is destroyed if they are heated above a certain temperature, called the Curie point. For most magnetic rocks and minerals, the Curie point is about 500 °C (Press and Siever, 1982). If a rock has been reheated, its paleomagnetic properties reflect the Earth's magnetic field at the time the rock cooled below its Curie point, not necessarily the geomagnetic field at the time the rock was formed.

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## Correspondence

*The following presents excerpts from letters to the editor or to the author, in response to the article "The case of the inverted auriferous paleotorrent—exotic quartzite gravels on Wallowa Mountain peaks," by J.E. Allen, published in the last issue of* Oregon Geology *(p. 104-107).*

Dear editor:

This has little (nothing?) to do with agriculture. I get *Oregon Geology* at home and just want to let you know how much I enjoy some issues.

The September issue is a prize to me. I learned a lot from the article on beach placers.

What really caught my eye and admiration was the wonderful headline on John Eliot Allen's article—"auriferous paleotorrent." What a great way to say the magic words that excite any gold buff—"ancient river of gold"!

I hope it was all on purpose. Even if it wasn't, the excitement arose.

—Sincerely,
Virgil Rupp, Editor
*Agri-Times Northwest*

Dear John:

I read with interest your writeup in *Oregon Geology* about the quartzite gravels. I congratulate you for publishing the article, and I hope you'll motivate someone to take a closer look at the problem.

I've been intrigued by the gravels since I first saw them in Hells Canyon in the early 60's. I even mentioned them in my dissertation after I found them on top of the limestone near McGraw and Spring Creeks. Last summer I spent three days in that area, digging down into pockets or holes in the karst-eroded limestone, carrying the soil from the bottoms of the holes to a stream, and panning for color. I found only black sand and no gold. *However, John, I **know** it's there!*

The thickest deposit (10 meters) is on top of the Martin Bridge Limestone south of the confluence of the Grande Ronde and Snake Rivers in Washington. There, the boulders and gravels are a mixture of greenstone, quartz diorite (Jurassic-Cretaceous), and quartzite.

I have found quartzite gravels in many places along the contact between the Permian-Triassic and Columbia River Basalt Group in the canyon. Even last summer, I found new deposits at Pittsburg Landing and in the Seven Devils Mountains. I also recall an extensive surface covered by the boulders and cobbles, on Joseph Mountain, I believe, in the Wallowas. Interestingly, there are well-rounded boulders and cobbles in other places within the Blue Mountains: south of Sparta and toward Baker City they have a mixture of rock types, including quartzite and chert (from the Baker terrane).

Origin? I doubt if we can ascribe it to a single stream. Rather, I think of an extensive area of coalescing alluvial fans (Bajadas) that formed in the Late Cretaceous-Miocene (probably -Eocene) interval at the foot of a spectacular mountain range caused by uplift of central Idaho. The mountain range may have formed as a consequence of the Blue Mountain island arc/North America collision and/or intrusion and uplift of the Idaho Batholith. The quartzites themselves are a problem, but I have noted that they may have been eroded from the quartzite beds in the Revelle Group of central and northern Idaho.

Anyway, John, if someone bites, let me know, and I'll help them find significant outcrops of boulders in the canyon.

Once again, congratulations! You have been a fantastic salesman on the geology of Oregon. Keep it up!

—Best regards,
Tracy Vallier
U.S. Geological Survey
Menlo Park, California

## Mineral information on Oregon now available as computer database

The Oregon Department of Geology and Mineral Industries (DOGAMI) has placed on open file a database containing a variety of information on minerals in Oregon.

**Mineral Information Layer for Oregon by County (MILOC)**, compiled by Jerry J. Gray.
DOGAMI Open-File Report O-91-4, 2 diskettes, $25.

MILOC is a database in dBase III+ format that can be imported into computerized geographic information systems or used with a personal computer as a stand-alone, county-by-county database. It provides information on approximately 7,650 mineral occurrences, prospects, and mines in Oregon. Records on individual sites include a great variety of data on location, commodity, geology, descriptions of mine workings, and many other subjects.

The database was developed in cooperation with several federal and state natural-resource agencies and will serve as a mineral-data layer to fit with other portions of a variety of geographic information systems. For that purpose, each site is located by latitude/longitude and Universal Transverse Mercator (UTM) coordinates.

MILOC is a useful information source for universal applications in industrial, county, state, and federal planning, exploration, and management.

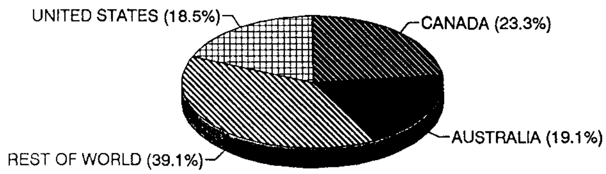
The new release, DOGAMI Open-File Report O-91-4, consists of two 1.2-megabyte (5¼-inch) high-density diskettes in MS-DOS format. It is now available at the DOGAMI Portland Office (address on p. 122 of this issue). Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

## Exploration spending for nonferrous metals reported

From a survey of current and recent exploration programs of 167 companies (representing at least 80 percent of worldwide exploration spending on nonferrous metals), the Metals Economics Group reports the following totals for 1991:

The 1991 exploration budgets of 153 companies worldwide, including expenditures for precious, base, and other nonferrous hard-rock metals, as well as diamonds and any industrial minerals sought by the mining companies surveyed, amount to a total of $1.846 billion.

Of this amount, 60.9 percent was directed to projects in Canada (23.3 percent, $430 million), Australia (19.1 percent, $353 million), and the United States (18.5 percent, $341 million). Canada's share, though still largest, has declined considerably since 1987 and 1988, when Canadian expenditures totaled more than $1 billion per year. U.S. expenditures have remained relatively stable during the past few years, while Australian expenditures have declined steadily since 1987.




*Worldwide 1991 exploration spending by location in 153 company budgets totaling $1.846 billion.*

Rough estimates of spending in other countries indicate that about $245 million is being spent in South Africa this year (13 percent of the surveyed total), $200 million in Latin America (11 percent), $125 million in the South Pacific area (7 percent), $80 million in Europe (4 percent), and $70 million (4 percent) in Africa outside South Africa. Small amounts of the surveyed budgets are being spent elsewhere, including Japan, China, India, and southeast Asia.

The ten largest spenders on exploration in 1991, with budgets ranging from $102 million to $44.2 million, include Anglo American, RTZ, CRA, Falconbridge, DeBeers, BHP, Noranda, Anglovaal, Placer Dome, and Western Mining. Together, these companies account for 35 percent of the surveyed exploration spending.

By the way, the complete study can be purchased for only $9,500 from Metals Economics Group, 200 Barrington Street, P.O. Box 2206, Halifax, Nova Scotia B3J 3C4, Canada, phone (902) 429-2880, FAX (902) 429-6593.

*—Metals Economic Group news release*

## DOGAMI has openings for volunteers

The Department of Geology and Mineral Industries (DOGAMI) has volunteers currently helping in the library and sales office, doing work that could not be done otherwise. These valued helpers have added much to DOGAMI, and their help is greatly appreciated.

We could use other volunteers, both in the new store/information center that will be opening next year (see page 136) and now in the library and the existing map and publications sales office. If you want to help where your contribution of time really makes a difference, contact Beverly Vogt, DOGAMI, 910 State Office Building, Portland, OR 97201, phone (503) 229-5580. □

## AGI publishes curriculum guide for earth-science content

*Earth Science Content Guidelines K-12* is an 80-page guide for incorporating earth-science content into the precollege curriculum. Published recently by the National Center for Earth Science Education of the American Geological Institute (AGI), the guide consists of a set of questions organized according to the interacting systems that characterize Earth and its relationship to the solar system. In each of the six content areas—solid Earth, air, water, ice, life, and Earth in space—the questions are divided into these grade levels: K-3, 3-6, 6-9, and 9-12.

The content-guide report also has a large section of notes outlining ideas that teachers might want students to understand while investigating the questions. The notes include suggestions for what teachers can do to help students acquire that understanding. They are arranged in a three-column format with the following column headings: Essential questions, Key ideas, and Seeking answers.

*Earth Science Content Guidelines K-12* is based on the set of goals, concepts, and recommendations for improving earth-science education in the nation's schools that was published by AGI earlier this year in a 40-page report, *Earth Science Education for the 21st Century: A Planning Guide.* This report discusses goals to guide earth-science education, essential concepts in earth science, recommendations for teaching earth science in grades K-12, and recommendations for implementing new precollege earth-science programs.

Both guides were developed by earth scientists, teachers, and other science educators with support from the National Science Foundation and other contributors. Copies are available from the AGI Publications Center, Box 2010, Annapolis Junction, MD 20701, phone (301) 953-1744. Volume discounts are available for each publication.

For more information about the content of the guides or AGI's education program, contact Andrew J. Verdon, Jr., National Center for Earth Science Education, AGI headquarters, 4220 King Street, Alexandria, VA 22302-1507, phone (703) 379-2480.

*—AGI news release*

## Washington geologic map adds second quadrant

The second quadrant of the geologic map of Washington has been completed and published. The first (southwest) quadrant was published in 1987 as Geologic Map GM-34.

**Geologic Map of Washington—Northeast Quadrant**, by K.L. Stoffel, N.L. Joseph, S.Z. Waggoner, C.W. Gulick, M.A. Korosec, and B.B. Bunning. Washington Division of Geology and Earth Resources Geologic Map GM-39, 1991, 36 p., 3 sheets, geologic map scale 1:250,000.

Price for folded sheets in thumb-notched envelope is $7.42 (plus $.48 tax for Washington residents only); flat sheets (limited supply, mailed in tubes) are $9.28 (plus $.72 Washington tax). The topographic base map is available separately as Map TM-2, folded or flat, for $1.86+$0.14=$2.00 or $3.25+$.35=$3.50, respectively.

Orders should be addressed to Department of Natural Resources, Division of Geology and Earth Resources, Mail Stop PY-12, Olympia, WA 98504. To each order, $1 should be added for postage and handling. □

# Early Oligocene paleoenvironment of a paleosol from the lower part of the John Day Formation near Clarno, Oregon

*by Aberra Getahun and Gregory J. Retallack, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403*

**ABSTRACT**

The red basal part of the lower Oligocene John Day Formation consists of numerous, superimposed fossil soils. One of these, reported here and named Luca clay paleosol[1], is a well-developed red clayey profile similar to modern Udalfs[2]. It represents a well-drained land surface that was stable for at least a few tens of thousands of years. It probably formed under forest vegetation, as can be judged from abundance of root traces and a well-developed subsurface clayey horizon. Its smectitic-kaolinitic clays and base-poor chemical composition are compatible with a sub-humid to humid paleoclimate.

## INTRODUCTION

The colorful badlands of mid-Tertiary nonmarine rocks in the high desert of the John Day country of central Oregon are a delight to the eye, well known from scenic landmarks such as the Painted Hills and Sheep Rock now protected within the John Day Fossil Beds National Monument. Only recently has it been realized that these striking color bands are ancient soils within tuffaceous deposits (Retallack, 1981, 1985).

This study of a fossil soil in the Oligocene part of the John Day Formation in north-central Oregon aims to provide a brief description of the paleosol and to interpret its significance for paleoenvironment and paleoecology of the area. The lower member of the John Day Formation, which rests unconformably on older rocks of the Clarno Formation, is composed mainly of brilliant red claystones and siltstones. The red color of the lower John Day Formation has been ascribed to mixing of volcanic ash with lateritic soil derived from the Clarno Formation (Waters and others, 1951; Fisher and Wilcox, 1960; Hay, 1962). In a later study Fisher (1964) explained the red clay as a continuation, into John Day time, of deep and prolonged weathering that was responsible for the post-Clarno "lateritic" paleosol. No exceptionally iron-rich rocks with evidence of irreversible hardening (plinthites or "laterites" formed in place) were found with the present work.

Association of iron oxides, manganese oxides, kaolinite, montmorillonite, chalcedony, and calcite also has been reported within the same hardpan in the lower John Day Formation (Fisher, 1964). These kinds of hardpans are sometimes found in desert soils (Birkeland, 1984). The present study, however, did not identify calcareous hardpans, either through acid testing in the field or through chemical analysis.

This is not to imply that lateritic and calcareous paleosols are not present but rather to indicate the diversity of prior views on ancient weathering in these rocks and emphasize the need for detailed study of entire profiles. There are many different kinds of paleosols in these rocks (Smith, 1988; Pratt, 1988) as in other alluvial sequences (Retallack, 1983; Bown and Kraus, 1987). The paleosol profile described here is a start at unravelling their complex and changing paleoenvironment through paleosol study.

[1] The word "luca" is the term for the color red in the Umatilla dialect of the Sahaptin language spoken by early inhabitants of this area (Rigsby, 1965).

[2] For explanations of soil-science terminology, readers are referred to Soil Conservation Service (1975), Brewer (1976), and Birkeland (1984).

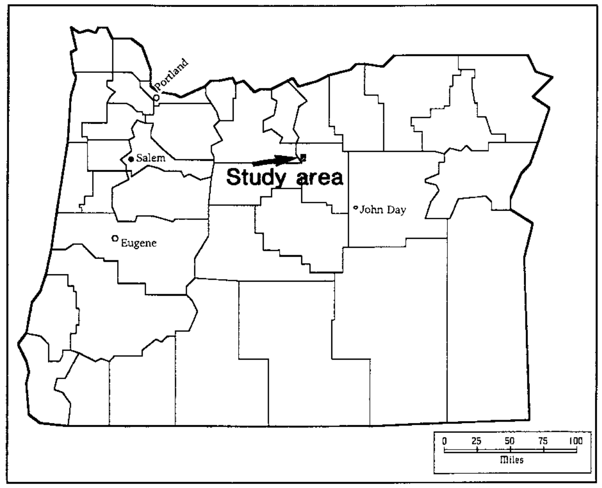



*Figure 1. Location of Luca clay paleosol study area in Wheeler County, Oregon.*

## GEOLOGIC SETTING

The studied profile is located in the north-central part of Wheeler County, Oregon, in the S½SE¼ sec. 23, T. 7 S., R. 19 E., Clarno 7½-minute quadrangle (Figure 1). It is some 2.5 mi northeast of the bridge across the John Day River at the small village of Clarno. The outcrop studied is a prominent red knoll capped with white ash, in a grassy slope 1 mi northeast of Camp Hancock (Figure 2). This red outcrop is mapped within the lower John Day Formation, which overlies the basal ignimbrite of the formation, here dated at 37.3±11 million years (m.y.) (Robinson and others, 1984). The basal red part of the formation, which includes the paleosol described here, is poorly fossiliferous. Loose around the base of the outcrop studied were found a fragmentary large canine tooth like that of an entelodont (large piglike mammal) and some permineralized woody branches 12 cm in diameter showing a fracture pattern similar to that of charcoal. Some 50 m south of the outcrop and underlying the paleosol are brown paper shales and tuffs containing fish scales, cones, winged fruits, and leaves, including those of *Ulmus*, *Tetrapteris*, and *Metasequoia*. All of these remains are low in diversity and poorly preserved compared to those of the middle green and upper buff members of John Day Formation, which contain abundant fossil leaves (Manchester and Meyer, 1987), fish (Cavender, 1969), insects (Cockerell, 1927; Peterson, 1964), and mammals (Merriam and Sinclair, 1907; Woodburne and Robinson, 1977).

The John Day Formation of north-central Oregon is a widespread, largely pyroclastic sequence lying between the Clarno Formation of Eocene age and the Columbia River Basalt Group of Miocene age. The formation crops out in a belt along the southern margin of the Columbia River drainage basin, extending nearly 200 km eastward from the central Oregon Cascade Range. The formation provides a well-exposed and relatively continuous record of early Cascade Range volcanism. It consists largely of andesitic to dacitic tuffaceous claystone, air-fall tuff with numerous interlayered ash-flow sheets, and lava flows of rhyolite and trachyandesite (Woodburne and Robinson, 1977; Dingus, 1979).

*Figure 2. General view of the lower John Day Formation, in Wheeler County, Oregon (arrow indicates position of Luca clay paleosol).*

## METHOD

A trench about 2.30 m deep and 80 cm wide was dug with hoe and shovel to create a better exposure of the various horizons of the paleosol. Dilute hydrochloric acid was used to check the presence of carbonate minerals. Color was identified using a Munsell color chart. Thin sections were made of samples from each horizon, and point counts were done. Chemical composition of each sample was assayed with atomic absorption by Christine McBirney at the University of Oregon. The clay minerals of the paleosol were identified by use of the Rigaku Miniflex X-ray diffraction machine. The detector was set to count over a range of 2θ from 70° to 5°. The X-ray wavelength was 1.54059 Å ($CuK_\alpha$). The samples analyzed were not pretreated. Quartz and silicon metal standards were used for calibrating the machine.

## DESCRIPTION OF THE LUCA CLAY PALEOSOL

The paleosols crop out in a red badlands slope (Figure 2). The top of the paleosol can be identified as a laterally abrupt contact between white ash and red mottled silty claystone. Below that, there is a thick gradational profile of claystone that becomes redder and darker in color as mottles of gray silty claystones become less abundant. The drab mottles are complexly interwined and tubular, like drab-haloed root traces (Retallack, 1983). The various horizons identified in the trench were a silty claystone surface (A), clayey subsurface (Bt), and a silty tuffaceous claystone parent material (C). Color varies from white (5YR8/1) in the A horizon to dusky red (10R3/4) and dark red (10R3/6) in the Bt and C horizons, respectively.

The A horizon (0-47 cm) is a noncalcareous silty claystone, containing slender, purple root traces surrounded by drab haloes. This horizon is sharply truncated by the overlying tuff unit that defines the top of the paleosol. The A horizon is dominantly clay with lesser silt. Slickensides also were observed. In thin section, it has porphyroskelic skelinsepic plasmic fabric (of Brewer, 1976); with plagioclase, volcanic rock fragments, glass shards, opaques, and a few sesquiargillans.

The Bt horizon (0.47-1.41 m) is a dusky red (10R3/4) claystone with less common drab-haloed root traces than the A horizon (Figure 3). This clayey horizon is riddled with slickensides, randomly arranged. Acid test indicates it is noncalcareous. There is a gradual decrease of the root traces downward into the C horizon. No fossil burrows or biological traces other than roots were found in this horizon. Microtexture is porphyroskelic skelmasepic, with plagioclase, volcanic rock fragments, opaques, and few quartz grains.

The C horizon (1.41-2.16 m) is dark red (10R3/6) and contains no root traces or burrows. The dominant grain size of this horizon is silt. This part of the paleosol gave no indication of a concentration of calcareous nodules or stringers. The lower portion of the horizon contains some recognizable feldspar grains and rock fragments (Figure 3). Microtexture is porphyroskelic skelmasepic in drab areas, isotic with sesquioxide stain elsewhere. Plagioclase, volcanic rock fragment, opaques, quartz, and a few sesquiargillans were also observed. The C horizon gradually passes into a clayey lower portion that also has been affected by weathering processes. It has the same color as the overlying horizon.

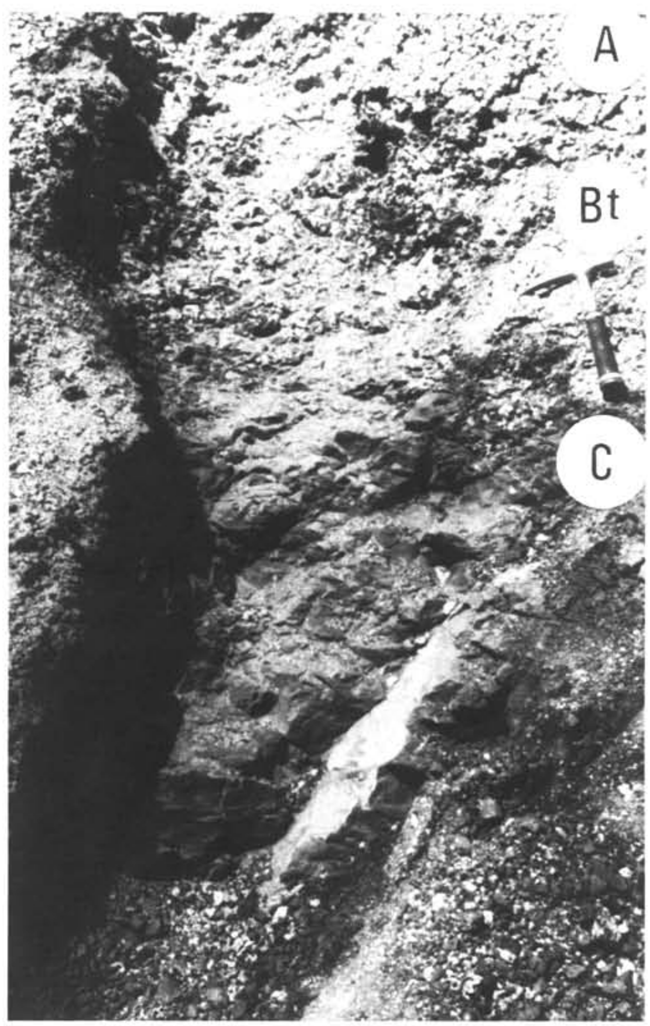



*Figure 3. Paleosol horizons exposed after trenching of the Luca clay paleosol.*

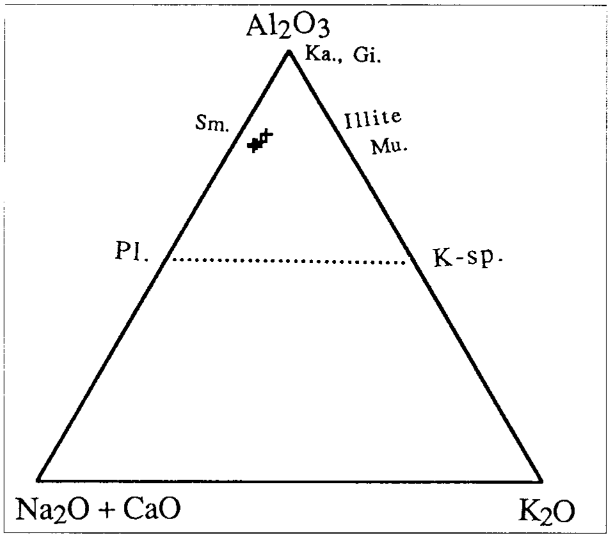



*Figure 4. Triangular variation diagram constructed using molar proportions of $Al_2O_3$, $Na_2O+CaO$, and $K_2O$ as end members for the weathering profile of Luca clay paleosol.*

Table 1. *Major- and trace-element chemical data for the Luca Clay paleosol. Oxides in weight percent, trace elements in ppm; sample numbers indicate vertical position between surface (JD-1) and lower horizon (JD-5)*

| Sample | JD-1 | JD-2 | JD-3 | JD-4 | JD-5 |
|---|---|---|---|---|---|
| $SiO_2$ | 59.46 | 59.26 | 57.68 | 53.20 | 51.50 |
| $TiO_2$ | 1.46 | 1.52 | 1.58 | 1.67 | 1.58 |
| $Al_2O_3$ | 16.13 | 16.20 | 16.42 | 17.17 | 17.36 |
| $Fe_2O_3$ | 5.31 | 5.59 | 6.75 | 8.85 | 10.20 |
| FeO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| MnO | 0.06 | 0.05 | 0.06 | 0.08 | 0.08 |
| MgO | 0.66 | 0.63 | 0.62 | 0.61 | 0.57 |
| CaO | 2.26 | 2.12 | 2.11 | 2.08 | 1.84 |
| $Na_2O$ | 1.57 | 1.54 | 1.51 | 1.37 | 1.21 |
| $K_2O$ | 0.80 | 0.82 | 0.92 | 1.03 | 1.08 |
| $H_2O^+$ | 3.65 | 3.60 | 4.50 | 4.28 | 4.36 |
| $H_2O^-$ | 8.68 | 8.56 | 7.65 | 9.75 | 10.34 |
| $P_2O_5$ | 0.09 | 0.10 | 0.08 | 0.13 | 0.07 |
| TOTAL | 100.13 | 99.70 | 99.88 | 100.18 | 100.19 |
| | | | | | |
| Ba | 135 | 135 | 145 | 116 | 126 |
| Co | 78 | 28 | 15 | 20 | 20 |
| Cr | 20 | 21 | 23 | 25 | 27 |
| Cu | 80 | 112 | 106 | 130 | 45 |
| Li | 16 | 16 | 16 | 15 | 17 |
| Rb | 42 | 41 | 59 | 57 | 70 |
| Sr | 134 | 128 | 124 | 100 | 94 |
| Zn | 82 | 82 | 86 | 89 | 86 |

## CLAY MINERAL COMPOSITION

Smectite is the dominant clay mineral followed by kaolinite, as revealed by X-ray diffraction studies. A triangular variation diagram plotted with $Al_2O_3$, $K_2O$, and $Na_2O$+CaO (following Nesbit and Young, 1989) as end members also indicates smectite to be the major clay component of the paleosol (Figure 4). Quartz and hematite also were detected in all the X-ray diffraction traces.

## CHEMICAL COMPOSITION

Within the profile there is a general increase in the oxide values of $SiO_2$, CaO, MnO, $Na_2O$, and MgO and decrease of $Fe_2O_3$, $K_2O$, $TiO_2$, and $Al_2O_3$ from the lower horizon to the surface of the paleosol (Table 1). Three main patterns appear in the distribution of the trace elements in the paleosol. Co, Ni, and Sr are found in larger abundance in the surface and near-surface horizon; Cr, Rb, and Zn are found in greater abundance in the lower horizon, while Cu and Ba are enriched in the clay-rich Bt horizon.

The concentration of $SiO_2$ and some mobile elements (alkali and alkaline earth elements) in the A horizon compared to the lower part of the fossil soil may have been due to the addition of volcanic ash, dust, and thin increments of flood-borne silt (which are evident from the profile section; Figure 5). The depletion of potassium from the A horizon could be the result of plant uptake as found in surface soils by Mehlich and Drake (1955) and Tan (1984).

In general, Ba, Cr, and Zn tend to accumulate in clays of soils and other residual materials (Aubert and Pinta, 1977; Wedepohl, 1978). The abundance of these elements and Cu in the clay-rich Bt horizon may reflect the affinity of these trace elements for clay and hydroxides of iron and manganese. The surface enrichment of Sr, generally a mobile element during weathering, may be due to addition of new materials to the soil profile.

## MOLECULAR WEATHERING RATIOS

Molecular ratios were employed to understand specific weathering processes in the development of the paleosol. The ratios are calculated by dividing the weight percent of each oxide or element involved by its molecular weight and then dividing the oxides or elements as specified by the particular ratio.

The ratios of $Al_2O_3/K_2O$, $SiO_2/Fe_2O_3$, $SiO_2/Al_2O_3$, Base/$Al_2O_3$, and Ba/Sr all decrease down the profile indicating leaching of bases and iron-rich clay from surface to subsurface horizons (Figure 6). The ratio of $FeO/Fe_2O_3$ is extremely low in all the horizons, evidence of a highly oxidized paleosol that was probably well-drained throughout. The Ba/Sr ratio of the Luca clay paleosol is also low throughout, an indication of limited leaching.

## DIAGENESIS

The drab-colored A horizon, which originally would have been the part of the paleosol richest in organic matter, may have been discolored during burial gleization of the paleosol. Drab-haloed root traces, abundant in both A and Bt horizons, may also have been discolored by anaerobic decay of organic matter soon after burial of the fossil soil (Retallack, 1983). These drab haloes and horizons have none of the features, such as ferruginous concretions or a tabular pattern of carbonaceous root traces, that are found in originally waterlogged soils. The paleosol is also too highly oxidized to have been a gleyed soil.

The red color of the soil matrix is due to the presence of hematite as revealed by X-ray diffraction. Well-drained soils may have hydroxides of ferric iron in the form of gels, or minerals such as goethite, which form a light-brown or yellow stain. These minerals may have been converted to hematite by dehydration during compaction of the fossil soil (Walker, 1967). Thus the paleosol may

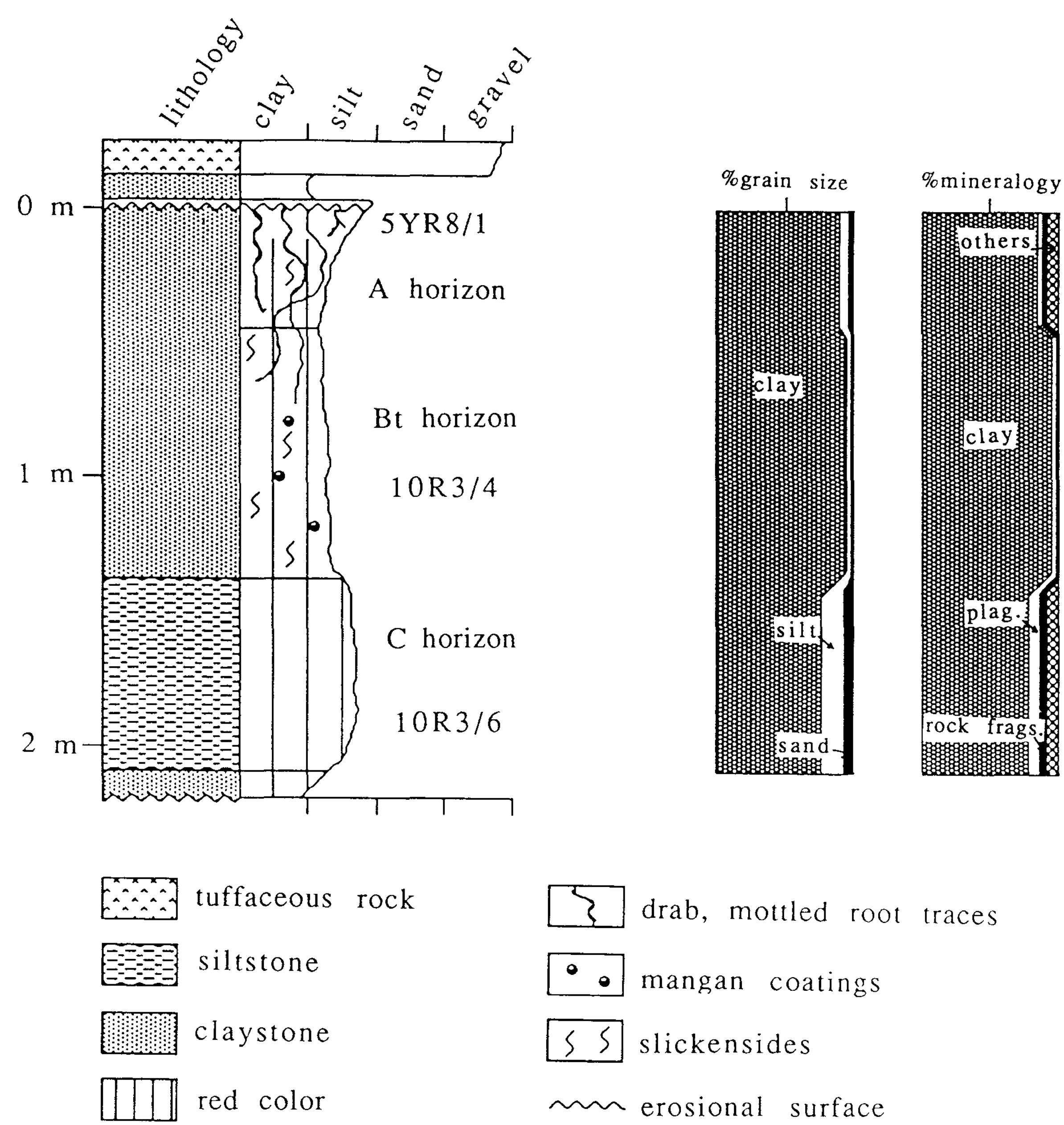



*Figure 5. Columnar section (measured in field) and petrographic composition and grain size (from point-counting of thin sections) of the Luca clay paleosol within the lower John Day Formation in Wheeler County, Oregon.*

be redder than the original soil by as much as three Munsell hue units, like some Quaternary paleosols compared to similar surface soils (Ruhe, 1969).

Compaction of paleosols by overburden is a common phenomenon that results in a reduction of their thickness. The deformed root traces of the Luca clay paleosol indicate a considerable reduction of thickness of the fossil soil by compaction. Slickensides form in clayey soils where peds are repeatedly heaved past one another or by crushing of peds one against another during compaction following burial (Retallack, 1990). Both of these mechanisms might have been the causes for the abundant slickensides observed in the paleosol. The smectitic nature of the clay (Figure 4) would have facilitated the swelling and shrinking of the soil upon wetting and drying.

## IDENTIFICATION

Modern soils with clayey subsurface (argillic) horizons include Alfisols and Ultisols, which are distinguished and classified according to their base status. The greater abundance of smectite than kaolinite indicates a mildly alkaline to neutral pH. The former Eh of the paleosol can be constrained within broad limits from mineral assemblages. Unlike a reducing environment, where soil hue is usually bluish or greenish gray and where root traces are confined to shallow depths and horizontally oriented, the Luca clay paleosol has a red hue and numerous branching and deeply penetrating root traces. This indicates an oxidizing environment during the development of the fossil soil.

From these considerations the paleosol can be classified as an Alfisol of Soil Conservation Service (1975). Considering its non-calcareous composition and depth of weathering, it probably was a Udalf.

## PALEOENVIRONMENT

### Climate

The absence of calcium carbonate and degree of leaching and base depletion indicated by molecular weathering ratios (Figure 6) within the horizons indicate humid conditions. The abundance of smectite and slickensides is compatible with moderate seasonality of wet and dry conditions during formation of this fossil soil. There is no pronounced evidence of clay heave (mukkara structure of Paton, 1974) as in Vertisols of strongly seasonal climate.

### Vegetation

The Luca clay paleosol is deeply weathered and has a full sequence of horizons (A—Bt—C). These features and abundant root traces that emanate from the surface down into the profile are evidence that it once supported a woodland or forest ecosystem. The drab-colored portions of the A and Bt horizons (Figures 2 and 3) may have formed during burial around areas once moderately rich in organic matter, as already outlined. This would probably have been an ochric epipedon of a well-drained soil rather than a histic one of a swampy soil. The charcoalified wood found near the paleosol may be taken as an indication of occasional forest fires. Fossil plants in a lacustrine deposit underlying the paleosol include *Ulmus*, *Tetrapteris*, and *Metasequoia*. This is similar to forest floras known from lake deposits higher in the John Day Formation (Manchester and Meyer, 1987), but such lakeside vegetation did not necessarily grow in the well-drained paleosol reported here.

### Animals

No burrows were recognized in the paleosol. A stout canine tooth like that of an entelodont was found loose on the surface near the base of this paleosol. This fossil is similar to those found higher on the John Day Formation (Merriam and Sinclair, 1907). Such stout teeth are more readily preserved than shells or porous bones, and the noncalcareous Luca clay paleosol would not have been especially favorable for the preservation of bones or teeth. Thus the paleosol may have supported a diverse mammalian fauna that remains poorly known because of preservational biases.

### Topographic setting

The Luca clay paleosol was formed on a stable land surface. The deeply penetrating and evenly spread root traces in the fossil soil are indications of high porosity, permeability and drainage. The red hue from hematite pigment of the Bt horizon probably formed by burial dehydration of iron oxyhydrates or gels (Walker, 1967). It is unlikely, however, that such a clayey soil interbedded with coarse-grained gray to white tuffs was oxidized during burial by ground water. Thus the very low molecular weathering ratio of $FeO/Fe_2O_3$ (Figure 6) can be taken as evidence of a strongly oxidized soil. The drab color of the A horizon was not caused by waterlogging but by anaerobic reduction of organic matter as the buried soil subsided below water table. The former water table was probably at least 3 m below the surface during soil formation.

### Parent material

The Luca clay paleosol formed on a volcanogenic tuffaceous material that probably had been reworked from preexisting soils and redistributed by rivers. The ratios of $SiO_2/Al_2O_3$, $SiO_2/Fe_2O_3$, and $FeO/Fe_2O_3$ at the base of the profile are unlike those of fresh ash and may have been produced by desilication and ferruginization in the drainage basin. Such processes continued during the development of the fossil soil from its parent material as revealed by these same molecular ratios (Figure 6).

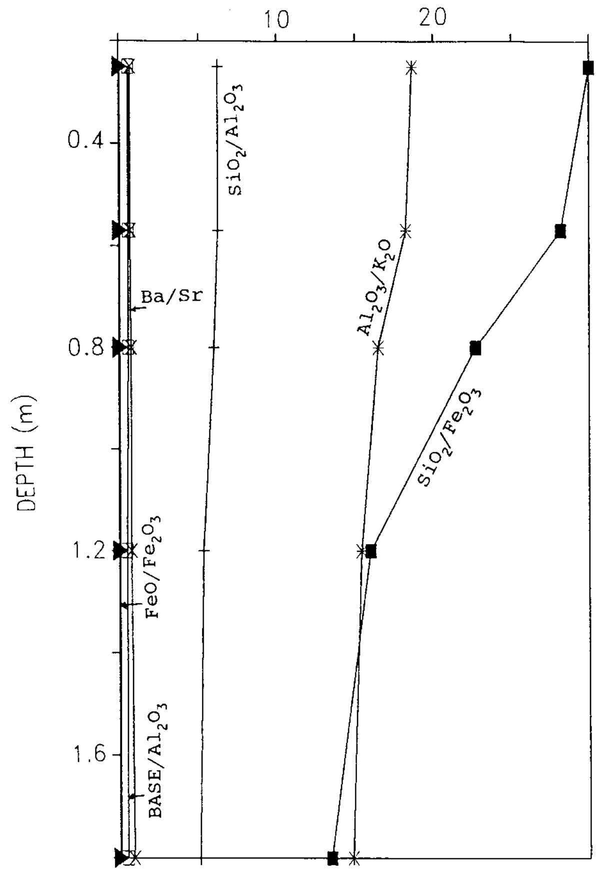



*Figure 6. Selected molecular ratios chosen to demonstrate degree of weathering of the Luca clay paleosol.*

### Time for formation

The clayey subsurface (Bt) horizon of the Luca clay paleosol is moderately developed (in the sense of Retallack, 1988). In soils of alluvial terraces of the Merced River in the San Joaquin Valley of central California (Harden, 1982) such differentiated argillic horizons take some 10,000 to 40,000 years to form. Similar estimates are gained by comparison with Bt horizons in a variety of other chronosequences of surface soils, as summarized by Birkeland (1984). Thus the development of the Luca clay argillic (Bt) horizon of the paleosol may also represent a few tens of thousand years.

## CONCLUSION

The Luca clay paleosol in the Oligocene lower John Day Formation is a well-preserved and differentiated paleosol with gray to white A horizon and dusky to dark-red clay-rich Bt and silty C horizon. Numerous drab-haloed root traces extend from the A into the Bt horizon. It was formed in a humid to subhumid climate on the well-drained and stable land surface of an extensive alluvial plain downwind of a major volcanic mountain range. These ancient soils were evidently vegetated by large trees, probably forest, similar to that in evidence from associated lacustrine leaf beds.

## ACKNOWLEDGMENTS

The authors are grateful to Mrs. Paula Carter and the Institute of International Education (IIE) branch office at San Francisco

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## DOGAMI to open natural-resource store/information center

The Oregon Department of Geology and Mineral Industries (DOGAMI) will open its new natural-resource information center/store when the new Portland State Office Building is completed in late February or early March of next year. Located on 800 Oregon Street NE near the Lloyd Center, the Convention Center, and MAX, Portland's light-rail system, the new building will house many state agencies, including DOGAMI.

DOGAMI's administrative offices, geologists, and library will be located on the ninth floor of the new structure. The 700-ft$^2$ store/information center, however, will be on the first floor, in the southeast portion of the building.

The purpose of the new store/information center is to make natural-resource and outdoor-recreation material readily available to Oregonians and visitors. It will continue to sell U.S. Geological Survey (USGS) maps and DOGAMI publications but will also handle material from other state and federal natural-resource agencies. The USGS has agreed to provide the facility with many of its educational and informational materials and has designated it as an Earth Science Information Center. A committee of representatives from several state agencies has developed the inventory policy for the store, and that policy is available from DOGAMI for anyone who wants to see it.

Several months ago, DOGAMI announced a store-naming contest. Numerous interesting and in some cases unusual names were submitted, and an outstanding winner was selected. The winning name, which we believe really summarizes our vision for the new facility, will be announced in connection with the opening of the store/information center, and the winner will receive the prize at that time.

DOGAMI is looking for volunteers to help in the new store/information center. If you like people, have interest or expertise in some aspect of Oregon's natural resources such as geology, plants, wildlife, birds, or forestry, want to learn more about any such subjects, or would like an opportunity to share your knowledge about Oregon with someone else, contact Beverly Vogt, DOGAMI, 910 State Office Building, Portland, OR 97201, phone (503) 229-5580. Training for the store/information center will start in January, but if you are not available then, we will have an ongoing training program, so our volunteers will be well prepared. If you want to help DOGAMI sooner than that, we have several volunteers working with us now and could use more to help us with the existing store and with planning and organizing the move to the new site.

Watch for more news about us. □

## THESIS ABSTRACTS

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

**I. Direction of maximum horizontal compression in western Oregon determined by borehole breakouts. II. Structure and tectonics of the northern Willamette Valley, Oregon,** by Kenneth S. Werner (M.S., Oregon State University, 1991), 159 p.

Elliptical borehole enlargements or "breakouts" caused by systematic spalling of a borehole wall due to regional maximum horizontal stresses were identified in 18 wells drilled in the Coast Range and Willamette Valley of western Oregon. The breakouts generally indicate a north-northwest to north-northeast orientation of maximum horizontal compression ($\sigma H_{max}$) that agrees with the predominant direction of $\sigma H_{max}$ determined from earthquake focal mechanisms, from post-middle Miocene structural features, and from alignments of Holocene volcanic centers in the Pacific Northwest. However, this orientation is inconsistent with the N. 50° E. convergence between the Juan de Fuca and North American plates determined by Riddihough (1984) from Juan de Fuca Plate magnetic lineations as young as 730 ka (the Brunhes-Matuyama boundary). The predominant north-northwest to north-northeast orientation of $\sigma H_{max}$ may be due to the complex interaction of a northwestward-moving Pacific plate driving into the Gorda and Juan de Fuca Plates and indirectly transmitting north-south compression across the strongly coupled Cascadia subduction zone into the overriding North American Plate. Alternatively, the predominant north-northwest to north-northeast orientation of $\sigma H_{max}$ may be due to a landward counterclockwise rotation of the direction of $\sigma H_{max}$ from N. 50° E. compression offshore to north-south compression in the Coast Range.

The northern Willamette Valley lies on the eastern flank of the broad north-northeast-trending Oregon Coast Range structural arch. Eocene to Oligocene marine sedimentary rocks crop out along the western side of the northern Willamette Valley and form a gently eastward dipping homocline. However, beneath the center of the Willamette Valley, Eocene to Oligocene strata are structurally warped up.

During the Eocene, several major volcanic centers subdivided the Coast Range forearc region into shallow to deep marine basins. Several such volcanic centers occur adjacent to the northern Willamette Valley and are associated with residual gravity anomaly highs and lineations.

The top of basalt in the northern Willamette Valley (middle Miocene Columbia River basalt except near the valley margins)

*(continued on next page)*

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*(continued on next page)*

is contoured based on petroleum exploration wells, water wells, and seismic-reflection data. It is structurally downwarped to an altitude of less than -500 m just north of Woodburn. The downwarp is bounded to the south by the northeast-trending Waldo Hills range-front fault and in part to the north by the northeast-trending Yamhill River-Sherwood fault zone.

The northwest-trending Mount Angel fault extends across the northern Willamette Valley between Mount Angel and Woodburn and deforms middle Miocene Columbia River basalt and overlying Pliocene and Miocene fluvial and lacustrine deposits. The top of Columbia River basalt is vertically separated, northeast side up, roughly 100 m based on seismic-reflection data near Woodburn, and 250+ m based on water-well data near Mount Angel. The Mount Angel fault is part of a northwest-trending structural zone that includes the Gales Creek fault west of the Tualatin basin; however, a connection between the Gales Creek and Mount Angel faults does not occur through Willamette River alluvial deposits.

A series of small earthquakes (6 events with $m_c$ = 2.0, 2.5, 2.4, 2.2, 2.4, 1.4) occurred on August 14, 22, and 23, 1990, with epicenters near the northwest end of the Mount Angel fault. Routine locations indicate a depth of about 30 km. The preferred composite focal mechanism is a right-lateral strike-slip fault with a small normal component on a plane striking north and dipping steeply to the west.

Both recent mapping of the Mount Angel fault and the recent seismicity suggest that the Gales Creek-Mount Angel lineament is similar to the Portland Hills-Clackamas River lineament found to the north. Together, these two lineaments may take up right-lateral strike-slip motions imposed on the upper plate by oblique subduction.

Boring Lava appears to occur extensively in the subsurface of the northeastern portion of the northern Willamette Valley, as seismic data indicate. Many of the faults in the area are interpreted to be largely caused by doming from influx of Boring magma or subsidence associated with evacuation of Boring magma. Such faults occur at Petes Mountain, at Parrett Mountain, along the Molalla River, and possibly near Curtis. The fault along the Molalla River appears to offset the Pleistocene (?) Rowland Formation 1 m.

**Systematic paleontology, stratigraphic occurrence, and paleoecology of halobiid bivalves from the Martin Bridge Formation (Upper Triassic), Wallowa terrane, Oregon**, by Christopher A. McRoberts (M.S., University of Montana, 1990), 156 p.

The form-genus "*Halobia*" probably represents several different *Posidonia* and *Daonella* descendants. Species-level, systematic survey of Martin Bridge *Halobia* results in synonymy of previously described species from the same locality and discovery of halobiid species new to the Wallowa terrane. Reexamination of type material suggests that *Halobia ornatissima* is

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_____Industry news
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a junior synonym for *H. superba* and *H. dilatata* a junior synonym for *H. halorica* and that *H. dalliana* and *H. symetricia* are junior synonyms for *H. radiata*.

Geologic mapping revealed that the Martin Bridge stratotype is broken by thrust and high-angle faults. From the stratotype, five structurally isolated blocks were identified for stratigraphic analysis. The blocks consist of dark, finely laminated shale, finely bedded limestone, and limestone conglomerate.

Limited biostratigraphic resolution was possible. The presence of *Discotropites*, *Anatropites*, *Halobia oregonensis*, and *H. superba* low in the section indicates a late Carnian age, whereas, higher up, *H. halorica* indicates an early to middle Norian age. The occurrence of *H. beyrichi* and *H. austriaca* indicates proximity to the Carnian-Norian stage boundary, although faulting has obscured its exact stratigraphic position.

Halobiids from the section primarily occur in shell beds within a dark, finely laminated calcareous shale, probably deposited in an anaerobic or dysaerobic basin. The shell beds are interpreted to be the result of an increase in biogenic deposition rather than a decrease in background sedimentation or erosional lag deposit. Apart from *Chondrites*, the halobiid-bearing sediments are devoid of any benthos and evidence of bioturbation.

Previous arguments for the life habit of *Halobia* as endobyssate, reclining, or swimming are reconsidered. Morphologic evidence suggests a loosely nestling epibyssate habit. Evidence for halobiid attachment sites is lacking. Possible attachment to an algal substrate, either rooted or floating, is suggested. *Halobia* was probably opportunistic. A long-lived larval stage along with possible attachment to floating algae may explain its unusual facies and broad geographic distributions.

**The carbonate petrology and paleoecology of Upper Triassic limestones of the Wallowa terrane, Oregon and Idaho,** by Michael T. Whalen (M.S., University of Montana, 1985), 151 p.

The Upper Triassic Martin Bridge Formation is exposed as a thick sequence of limestone in Hells Canyon along the Idaho-Oregon border. The allochthonous structural setting and low-latitude origin of the Martin Bridge Formation and underlying Seven Devils Group, which comprise the Wallowa terrane, are fairly well established. A slightly younger unit, the Mission Creek limestone, is exposed about 25 km southeast of Lewiston, Idaho, along Mission Creek. This unit is stratigraphically and structurally isolated, and its exact relationship with the Martin Bridge Formation is unclear.

Through stratigraphic and petrographic analysis of these limestones I have ascertained that the Martin Bridge Formation was deposited first under supratidal conditions and then as intertidal and shallow subtidal platform deposits. Isolation of these carbonates from a cratonic sediment source is indicated by the absence of terrigenous sediments. The Martin Bridge Formation in Hells Canyon has been subjected to at least eight diagenetic processes that obscured many of the original depositional textures. Well-preserved fossils occur in coarse grainstone tempestites in the Martin Bridge Formation in Hells Canyon. The fossils were preferentially silicified, and their external morphology is well preserved. Epifaunal, suspension-feeding bivalves and spongiomorphs dominate the assemblage and indicate a relatively shallow, warm-water depositional setting.

The Mission Creek limestone was also deposited in warm, shallow water as evidenced by the silicified fossil assemblage dominated by red algae, spongiomorphs, and corals that formed small framework buildups. The lithology and the fauna of the Mission Creek limestone differ form those of the Martin Bridge Formation, and the Mission Creek appears to be younger in age.

Post-Triassic plate-tectonic movement transported, rotated, and accreted the allochthonous Wallowa terrane to the continental margin of North America. This terrane may be correlative with the coeval Wrangellia Terrane of southeastern Alaska and Vancouver Island but the existing evidence does not establish that they once formed a contiguous fragment of the earth's crust.

**Distribution of sand within selected littoral cells of the Pacific Northwest,** by Don J. Pettit (M.S., Portland State University, 1990), 249 p.

Beach sand acts as a buffer to wave energy, protecting the shoreline from erosion. Estimates of the quantity and distribution of beach sand in littoral cells of the Pacific Northwest (PNW) are critical to the understanding and prediction of shoreline erosion or accretion. This study was initiated in order to (1) document the distribution of sand in littoral cells of the PNW, (2) determine the factors which have brought about these present distributions, and (3) address the relationship of beach sand distribution to shoreline stability.

Eight littoral cells were chosen to represent the variety of smaller cells present in the PNW. The eight littoral cells are the La Push and Kalaloch cells of Washington, the Cannon Beach, Otter Rock, Newport, and Gold Beach cells of Oregon, and the Crescent City and Eureka cells of northern California. Aerial photographs were analyzed for the eight cells: photo sets taken before and after the 1983-1987 El Nino-related erosion event. Data on beach width and orientation and on terrace location and height were collected from maps and aerial photographs for analysis. Forty-six beaches in the eight littoral cells were surface-profiled to mean low-low water using standard surveying techniques and were surveyed geophysically to determine the depth to the wave cut platform. The results of the surveys were used to estimate the area and volume of sand in each of the selected cells. Slopes of the beach face and beach widths were determined from the survey results. Sand samples were collected at mid-beach face from 48 beaches within the selected cells, as were representative samples from 22 terraces. Grain-size analyses were performed for the collected beach and terrace samples in order to develop information on possible sources and direction of transport for the beach sand.

Results of the study indicate that beach sand distribution within littoral cells of the PNW varies as a function of (1) proximity to sand sources such as rivers, terraces, and the presence of relict sands; (2) location of sand sinks such as dune fields and estuaries; (3) shoreline orientation; (4) shoreline configuration; (5) the direction of net sediment transport within the littoral zone; and (6) the location of barriers to sand transport. Based on sand distributions and grain-size trends, the net transport direction of sediment is to the north within the Cannon Beach, Otter Rock, Newport, Crescent City, and Eureka cells. The net transport direction is to the south for the northern third of the Kalaloch cell, while the southern two-thirds show net transport to the north. The Gold Beach cell shows both north and south transportation of sediments—-away from the abrupt change in shoreline orientation in the Redhouse Beach to High Tide Beach area. The net littoral drift of the La Push cell similarly shows a diversion of beach sand to the south and north from an area near the middle of the cell.

The potential for erosion of a given area is related to (1) the total quantity of source sands available on a given beach and, more importantly, (2) the quantity of sand above mean high-high water (MHHW) on each beach. The sand above MHHW is important because it is this sand that acts as the final buffer to storm-wave attack. There is a high correlation between areas experiencing erosion and those areas which have the least sand in storage above mean high-high water within a littoral cell. □

# MINERAL EXPLORATION ACTIVITY

## MAJOR MINERAL EXPLORATION ACTIVITY

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Baker 1990 | Baboon Creek Chemstar Lime, Inc. | T. 19 S. R. 38 E. | Lime-stone | Expl |
| Baker 1990 | Cracker Creek Mine Simplot | T. 8 S. R. 37 E. | Gold | Expl |
| Baker 1991* | Aurora Ridge Western Consolidated Mines | T. 10 S. Rs. 35.5, 36 | Pre-cious Metals | Expl |
| Baker 1991 | Cave Creek Nerco Exploration | Tps. 11, 12 S. R. 42 E. | Gold | App |
| Baker 1991* | Gold Hill Golconda Resources | T. 12 S. R. 43 E. | Gold | App |
| Baker 1991* | Gold Powder Kennecott Expl. Co. | Tps. 9, 10 S. Rs. 41, 42 E. | Gold | Expl |
| Baker 1991 | Gold Ridge Mine Golconda Resources | T. 12 S. R. 43 E. | Gold | Expl |
| Baker 1991 | Lower Granview Earth Search Sciences | T. 14 S. R. 37 E. | Gold | App |
| Baker 1992 | Pole Creek Placer Dome U.S. | T. 13 S. R. 36 E. | Gold, silver | Expl |
| Coos 1991 | Seven Devils Oreg. Resources Corp. | Tps. 2, 7 S. R. 4 W. | Gold | Expl com |
| Crook 1988 | Bear Creek Independence Mining | Tps. 18, 19 S. R. 18 E. | Gold | Expl |
| Grant 1991 | Buffalo Mine American Amex | T. 8 S. R. 35½ E. | Gold | App |
| Grant 1991 | Canyon Mtn. Cammtex International | T. 13 S. R. 32 E. | Gold | Expl |
| Grant 1992 | Standard Mine Bear Paw Mining | T. 12 S. R. 33 E. | Gold, copper | Expl |
| Harney 1990 | Pine Creek Battle Mtn. Exploratn. | T. 20 S. R. 34 E. | Gold | Expl |
| Harney 1991* | Buck Mtn.-North Teck Resources, Inc. | T. 24 S. R. 36 E. | Gold | App |
| Harney 1991 | Flagstaff Butte Noranda Exploration | Tps. 3, 9 S. R. 37 E. | Gold | App |
| Jefferson 1991 | Red Jacket Bond Gold | Tps. 9, 10 S. R. 17 E. | Gold | App |
| Josephine 1990 | Martha Property Cambiex USA | T. 33 S. R. 5 W. | Gold | Expl |
| Lake 1988 | Quartz Mountain Wavecrest Resources. | T. 37 S. R. 16 E. | Gold | Expl |
| Lake 1990 | Glass Butte Galactic Services | Tps. 23, 24 S. R. 23 E. | Gold | Expl |
| Lake 1991 | 8th Drilling Series Wavecrest Resources | T. 37 S. R. 17 E. | Gold | Expl |
| Lincoln 1991 | Iron Mtn. Quarry Oreg. St. Highw. Div. | T. 10 S. R. 11 W. | Basalt | App |
| Linn 1991 | Hogg Rock Oreg. St. Highw. Div. | T. 13 S. R. 7½ E. | Rock | App |
| Linn 1991 | Quartzville Placer Dome U.S. | T. 11 S. R. 4 E. | Gold, silver | App |
| Malheur 1988 | Grassy Mountain Atlas Precious Metals | T. 22 S. R. 44 E. | Gold | Expl, com |
| Malheur 1988 | Harper Basin Project Amer. Copper & Nickel | T. 21 S. R. 42 E. | Gold | Expl |
| Malheur 1988 | Jessie Page Chevron Resources | T. 25 S. R. 43 E. | Gold | Expl |

MAJOR MINERAL EXPLORATION ACTIVITY (continued)

| County, date | Project name, company | Project location | Metal | Status |
|---|---|---|---|---|
| Malheur 1988 | Kerby Malheur Mining | T. 15 S. R. 45 E. | Gold | Expl, com |
| Malheur 1989 | Hope Butte Chevron Resources | T. 17 S. R. 43 E. | Gold | Expl, com |
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| Malheur 1990 | Calavera NERCO Exploration | T. 21 S. R. 45 E. | Gold | Expl |
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| Marion 1990 | Bornite Project Plexus Resources | T. 8 S. R. 3 E. | Copper | App com |

Explanations: App=application being processed. Expl=Exploration permit issued. Veg=Vegetation permit. Com=Interagency coordinating committee formed, baseline data collection started. Date=Date application was received or permit issued. *=New site

**Status changes**

The exploration permit program has been in effect for one year. There are 55 active permits or applications. The Katey project in Malheur County was taken over by Atlas Precious Metals from ASARCO. The name change from Freeport McMoRan to Independence on the Bear Creek project in Crook County is due to a corporate name change.

**Regulatory Issues**

Major legislation affecting the permitting procedure for heap-leach mining required changes to the rules of the Departments of Geology and Mineral Industries (DOGAMI), Environmental Quality (DEQ), Fish and Wildlife (ODFW), and Water Resources (WRD), plus minor changes in the rules of a few additional agencies. The DOGAMI Governing Board has adopted most of the implementing rules; adoption may be completed at the Board's November meeting. DEQ has held hearings on proposed rules relative to water quality; the Environmental Quality Commission reviewed the issues involved at an October work session. Adoption of the final DEQ rules are expected later this year. ODFW and WRD are both in the process of revising their rules.

Questions or comments should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office of the Oregon Department of Geology and Mineral Industries, 1534 Queen Avenue SE, Albany, OR 97321, telephone (503) 967-2039. □

## Salem club exhibits minerals

The Willamette Agate and Mineral Society of Salem has provided and installed the new exhibit in the display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem.

The current display represents the great variety of treasures from 15 Oregon counties: Pelecypod and gastropod fossils from the coast of Curry and Lincoln Counties; petrified wood, including a small piece of myrtle wood; nodules, including a Thistle Creek nodule that shows what appears to be a snow-covered scenery of tall trees; angel-wing and Maury Mountain moss agate; carnelian, including a large specimen, cabochons, and a pendant; "Chicken Track" jasper from Malheur County; realgar; spheres made from basalt and obsidian; nickel ore; and carvings made from soapstone and serpentine. Oregon's state rock, the Thunderegg, is represented by several polished halves; and Oregon's state gemstone, the Oregon Sunstone, is shown in rough and faceted specimens.

The display will remain in place until January 15, 1992.

*—OCRMC news release*

## Mist Gas Field area study available

**Northwest basin study (NBS-1) of the Nehalem-Astoria subbasins, Columbia and eastern Clatsop Counties, northwest Oregon** (1991), has been produced by R.J. Deacon and C.J. Newhouse of Portland, Oregon. It covers the Mist Gas Field area and consists of the following:

- Four sheets of correlation stratigraphic cross sections (see illustration) showing the Mist Gas Field and other potential sand reservoirs. Vertical scale is 1 inch = 500 ft, horizontal scale is 1 inch = 4,000 ft. Sheet size ranges from 25 by 30 inches to 31 by 45 inches.
- One 30- by 42-inch exploration map showing topography, producing wells, dry holes, location of stratigraphic sections, and source-rock maturation diagrams on three wells.

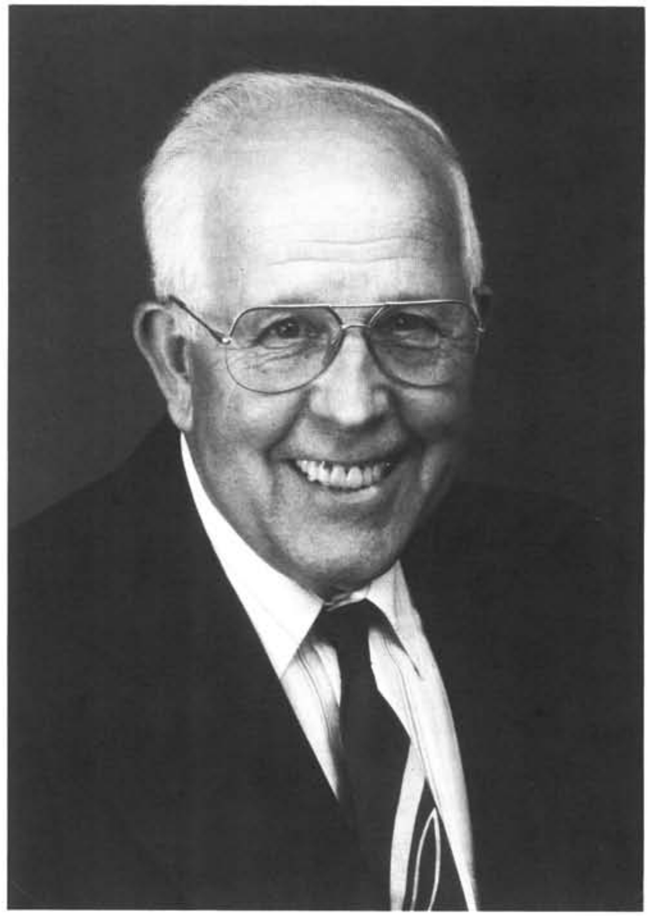
The full set is available from Newhouse/Deacon, 4204 SW Condor, Portland, OR 97201. The price is $245 plus postage.

*—Northwest Basin Studies news release*

## Melvin Ashwill honored

Melvin S. Ashwill of Madras, Oregon, was selected by the Council of the Paleontological Society as the 1991 recipient of the Strimple Award. This highly prestigious national award recognizes the outstanding contributions of an amateur to the science of paleontology.

The award was presented at the annual banquet of the Paleontological Society during the 1991 national meeting of the Geological Society of America in San Diego in late October. Steven R. Manchester of the Florida Museum of Natural History was his citationist, and Ashwill's acceptance statement will be printed in the *Journal of Paleontology.*



*Melvin S. Ashwill*

Ashwill is well known to *Oregon Geology* readers for his contributions on a variety of geologic topics, especially paleobotany. Most recently he has summarized his knowledge of the discipline for us in papers on the history of paleontology in Oregon (December 1987) and on guidelines for collecting fossils in Oregon (July 1989).

Ashwill also maintains a private fossil museum next to his home in Madras. He will show his considerable collection to interested persons or groups by appointment. His phone number is (503) 475-2907.

We are very pleased to see such national recognition of Ashwill's work. We congratulate him most heartily and wish him many more years of fruitful work as a most accomplished paleontologist.

*—The editors*

# Index to *OREGON GEOLOGY*, volume 53, 1991

*Numbers refer to volume and beginning page of entry. Most subject entries include cross-references to author entries (in parentheses).*

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