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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, an ASCII 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 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

Cover photo

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 intra-oceanic 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

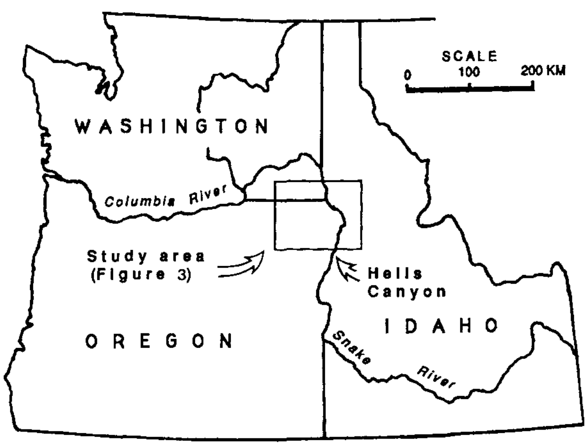

Figure 1. Index map of the northwestern United States showing the location of the study area.

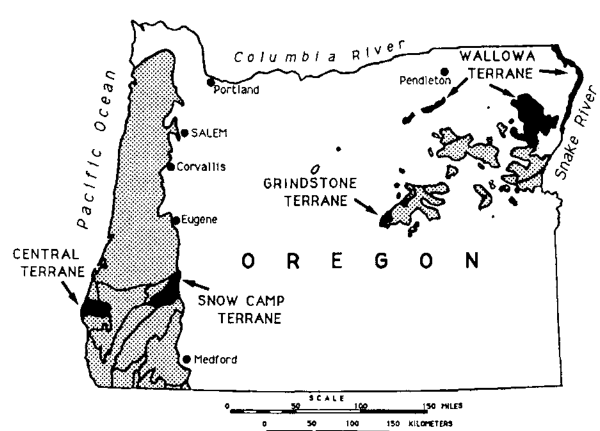

Figure 2. Map showing where suspect terranes (shaded areas) are exposed in Oregon. The four terranes that contain plant fossils are darkly shaded and identified. Adapted from Silberling and others (1987).

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

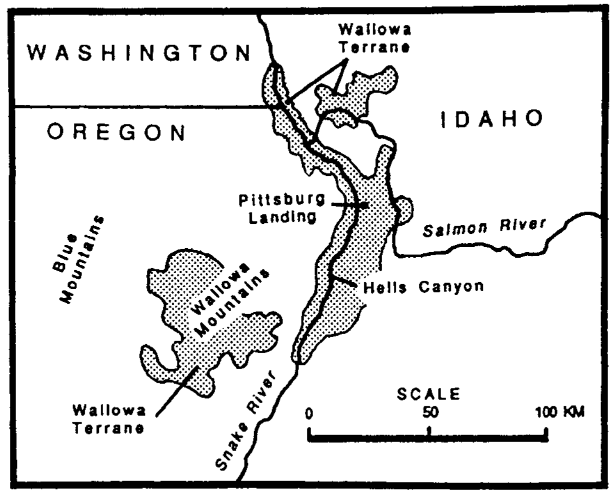

Figure 3. Map of Hells Canyon and adjacent areas in the northwestern United States. Adapted from Silberling and others (1987).

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.

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. *Dicksonia oregonensis* *Adiantites* sp. *Cladophlebis* sp.
Seed Ferns	*Sagenopteris* sp.
Ginkgoes	*Ginkgo huttonii*
Conifers	*Podozamites* sp. *Pagiophyllum* sp. *Brachyphyllum* sp. *Mesembrioxylon* sp.

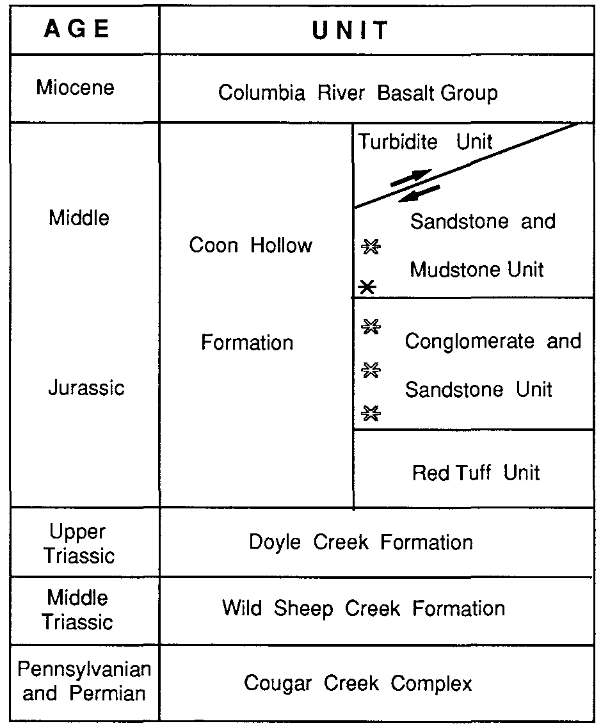

Figure 4. Stratigraphic section of the pre-Quaternary strata exposed in the Pittsburgh Landing area of the Hells Canyon, Idaho and Oregon. The open asterisks indicate the approximate stratigraphic position of plant localities in the Coon Hollow Formation. The solid asterisk indicates the approximate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

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.

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.

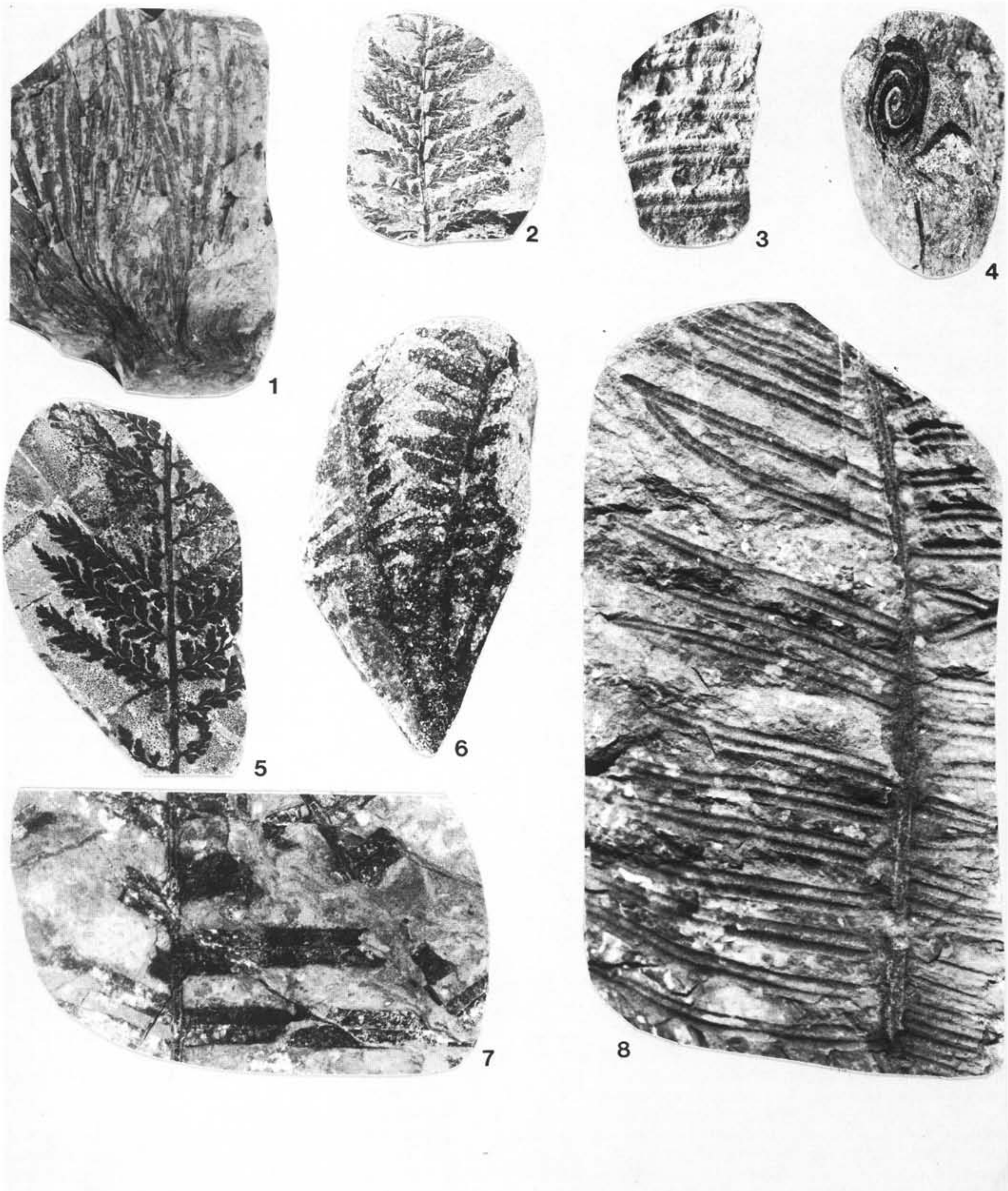

Plate 1. 1. Leaves and upper part of the corm (stem) of Isoetites *n. sp., x1. 2 and 5. A portion of the highly dissected leaves of the fern* Dicksonia oregonensis, *x1. 3. Fragments of the fertile pinnules of the fern* Phlebopteris *n. sp. bearing a row of round sori on either side of the pinnule midrib, 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.

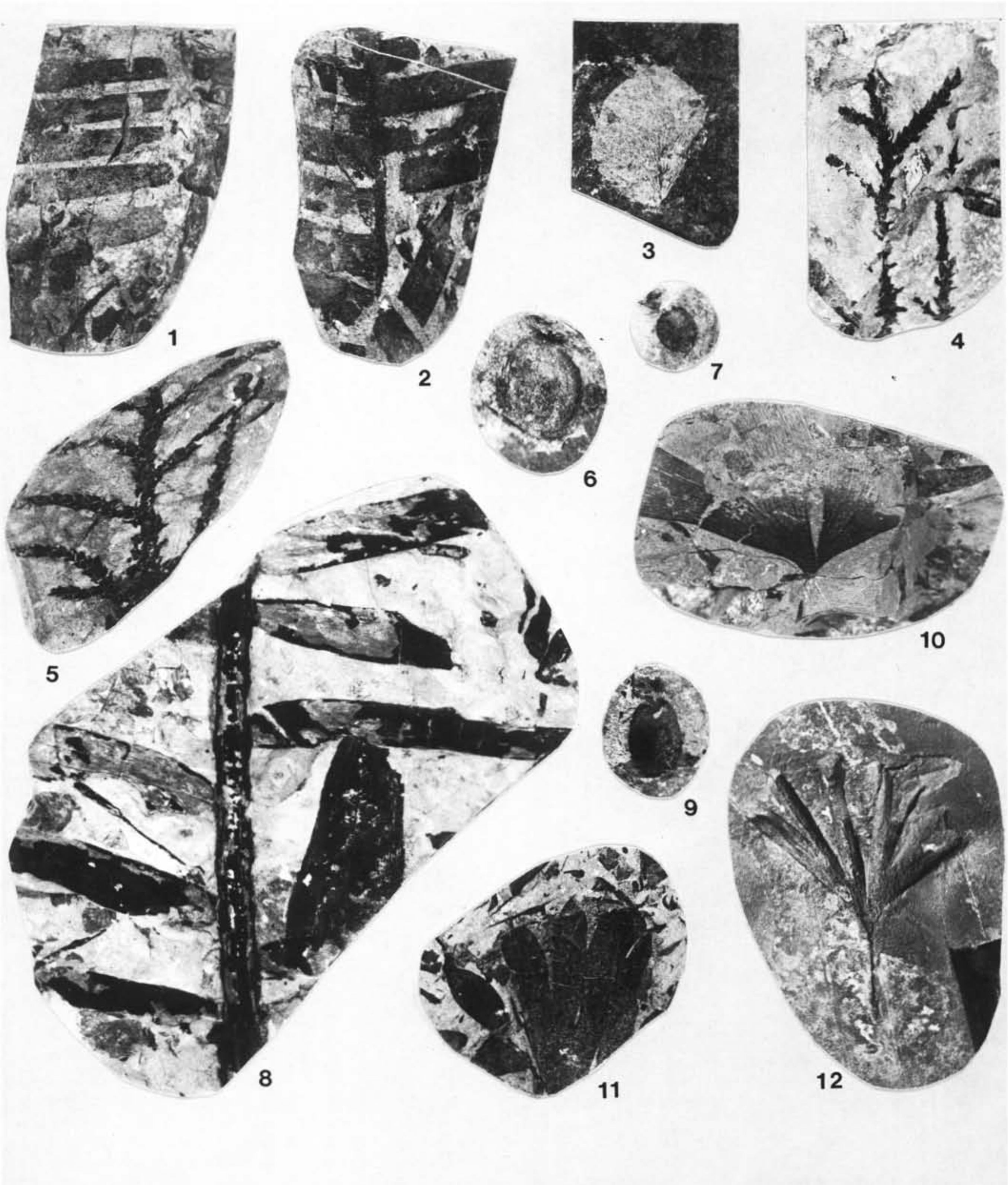

Plate 2. 1 and 2. Fragments of two unidentified cycadophyte leaves, x1. 3. A leaflet of the seed fern Sagenopteris. *The net venation which is typical of this species is visible along the midrib of the fossil, x1. 4. Portion of a leafy shoot of the conifer* Pagiophyllum. *Note the resemblance of the 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

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REFERENCES CITED

Ash, S.R., 19805, Upper Triassic floral zones of North America, *in* Dilcher, D.L., and Taylor, T.N.T., eds., Biostratigraphy of fossil plants: Stroudsburg, Pa., Dowden, Hutchinson and Ross, Inc., p. 153-270.

———in press, A new Jurassic *Phlebopteris* (Plantae, Filicales) from the Wallowa terrane in the Snake River Canyon, Oregon and Idaho: Journal of Paleontology, v. 65.

Ash, S.R., and Pigg, K., in preparation, A new Jurassic *Isoetites* (Isoetales) from the Wallowa Terrane in Hells Canyon, Oregon and Idaho: American Journal of Botany.

Barnard, P.D.W., 1973, Mesozoic floras: Palaeontological Association Special Paper 12, p. 175-187.

Bell, W.A., 1956, Lower Cretaceous floras of western Canada: Geological Survey of Canada Memoir 285, 331 p.

Brown, J.T., 1972, The flora of the Morrison Formation (Upper Jurassic) of central Montana: Missoula, Mont., University of Montana doctoral dissertation, 60 p.

Coney, P.J., Jones, D.L., and Monger, J.W.H., 1980, Cordilleran suspect terranes: Nature, v. 288, p. 329-333.

Creber, G.T., and Chaloner, W.G., 1984, Influence of environmental factors on the wood structure of living and fossil trees: Botanical Review, v. 50, p. 358-448.

Fontaine, W.M., 1900, Part II, The Jurassic flora, *in* Ward, L.F., Fontaine, W.M., Wanner, A., and Knowlton, F.H., Status of the Mesozoic floras of the United States: U.S. Geological Survey 20th Annual Report, pt. 2, p. 334-422.

———1905a, The Jurassic flora of Douglas County, Oregon, *in* Ward, L.F., Fontaine, W.M., Bibbins, A., and Wieland, G.R., Status of the Mesozoic floras of the United States (second paper): U.S. Geological Survey Monograph 46, p.48-145.

———1905b, Report on the various collections described above. 1. Plants from Curry County, Oregon, *in* Ward, L.F., Fontaine, W.M., Bibbins, A., and Wieland, G.R., Status of the Mesozoic floras of the United States (2nd paper): U.S. Geological Survey Monograph 46, p. 148-151.

Fry, W.L., 1964, Significant aspects of the Late Jurassic flora from the Monte de Oro Formation of northern California (abs.): Geological Society of America Special Paper 76, p. 64-65.

Jones, D.L., Silberling, N.J., and Hillhouse, J.W., 1977, Wrangellia—a displaced terrane in northwestern North America: Canadian Journal of Earth Science, v. 14, p. 2565-2577.

Knowlton, F.H., 1916, A Lower Jurassic flora from the upper Matanuska Valley, Alaska: U.S. National Museum Proceedings, v. 51, p. 451-460.

Lapasha, C.A., and Miller, C.N., Jr., 1985, Flora of the Early Cretaceous Kootenai Formation in Montana, Bryophytes and tracheophytes excluding conifers: Palaeontographica, part B, v. 196, p. 11-145.

Mamay, S.H., and Read, C.B., 1956, Additions to the flora of the Spotted Ridge Formation in central Oregon: U.S. Geological Survey Professional Paper 274-I, p. 211-226, pls. 34-37.

May, S.R., and Butler, R.F., 1986, North American Jurassic apparent polar wander: Implications for plate motion, paleogeography, and Cordilleran tectonics: Journal of Geophysical Research, v. 91, p. 11,519-11,544.

Newton, C.R., 1986, Late Triassic bivalves of the Martin Bridge Limestone, Hells Canyon, Oregon: Taphonomy, paleoecology, paleozoogeography, *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. 7-22.

Silberling, N.J., Jones, D.L., Blake, M.C., Jr., Howell, D.G., 1987, Lithotectonic terrane map of the western conterminous United States (Folio of the lithotectonic terrane maps of the North American Cordillera): U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-C.

*(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 southwest 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 postglacial 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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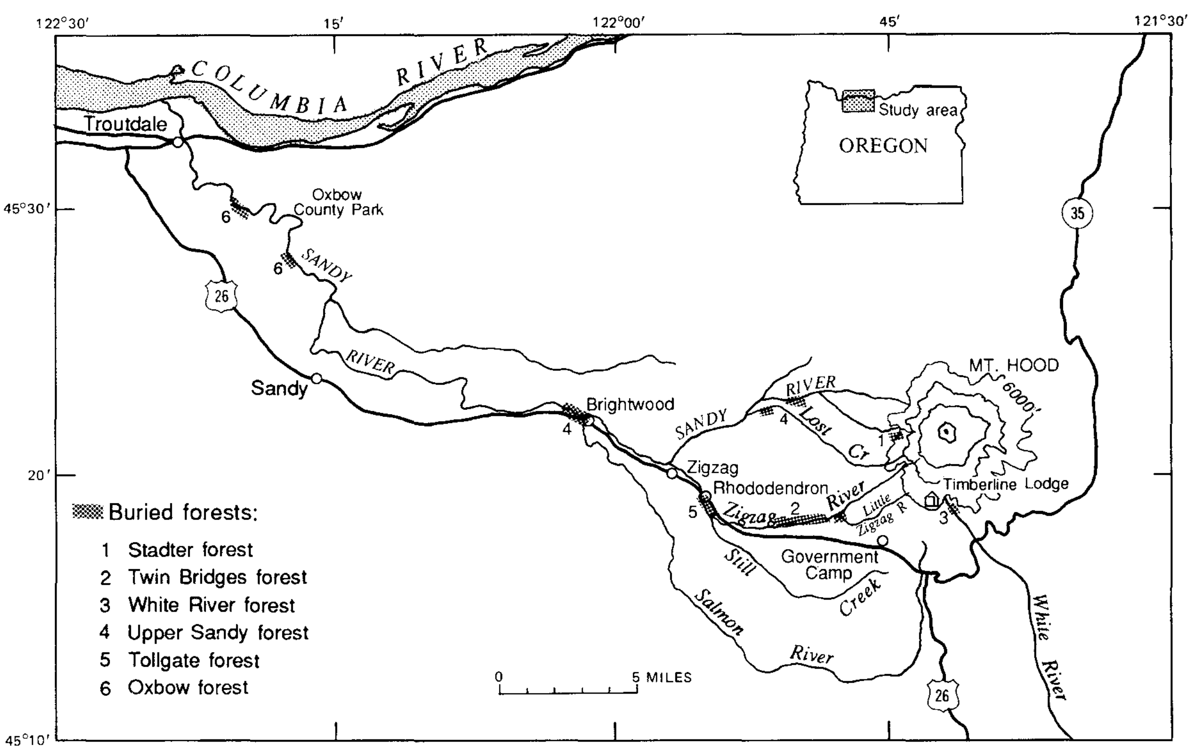

Figure 1. General location map to the known buried forests of Mount Hood.

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.

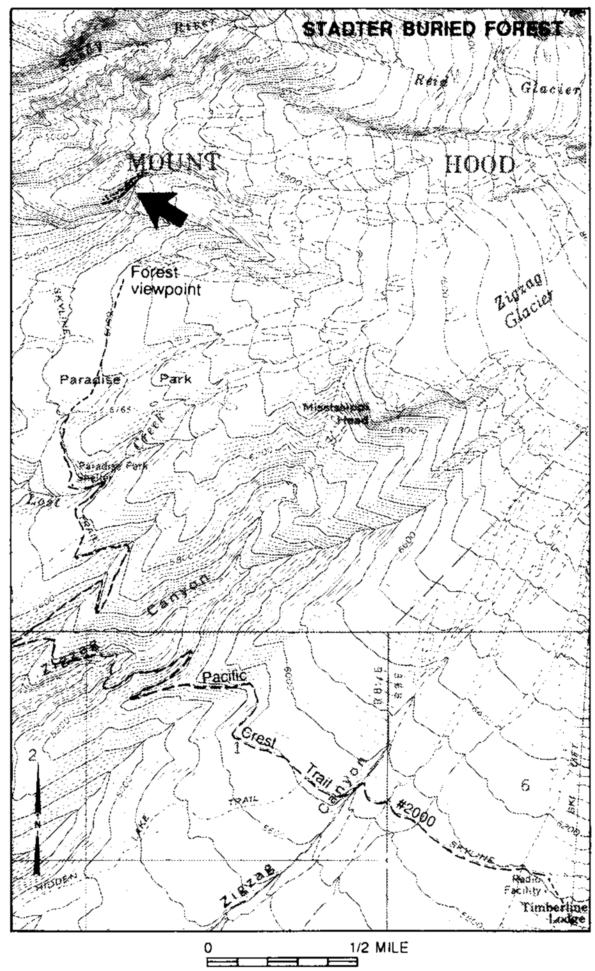

Figure 2. Location (stippled area in northwest quadrant of map) and access map for the Stadter buried forest. Base is from Mount Hood South 7½-minute quadrangle.

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.

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.

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

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

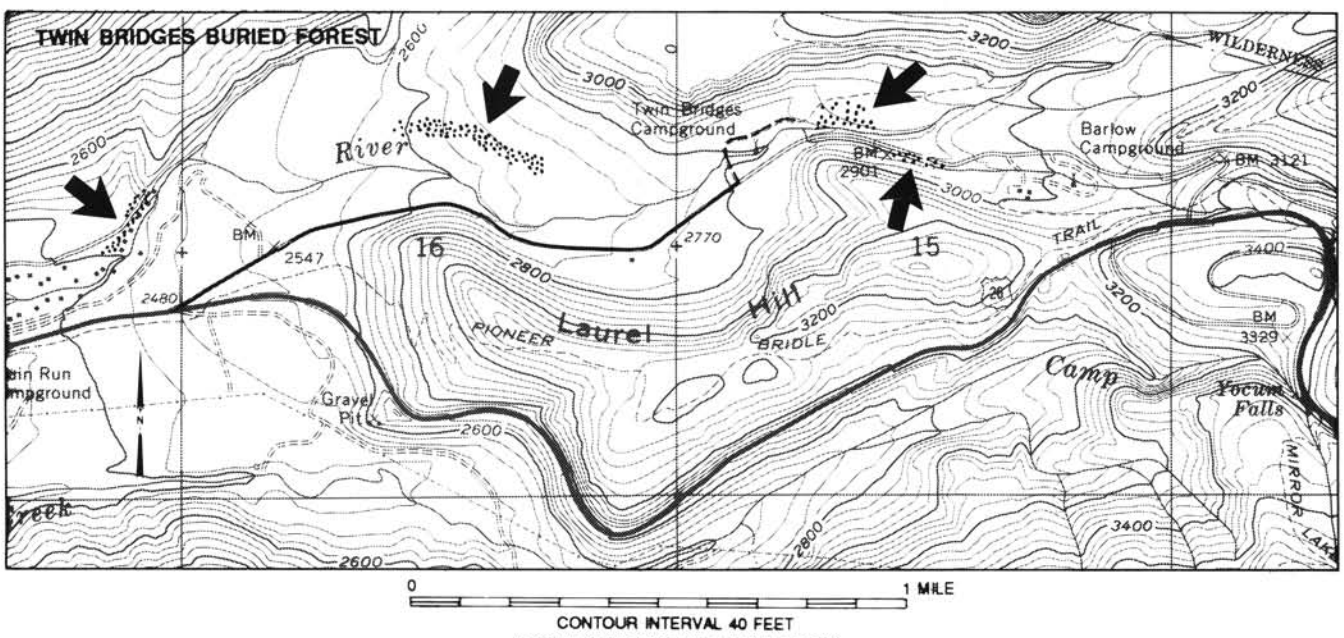

Figure 4. Location (stippled areas) and access map for the Twin Bridges buried forest. Base is from Government Camp 7½-minute quadrangle.

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.

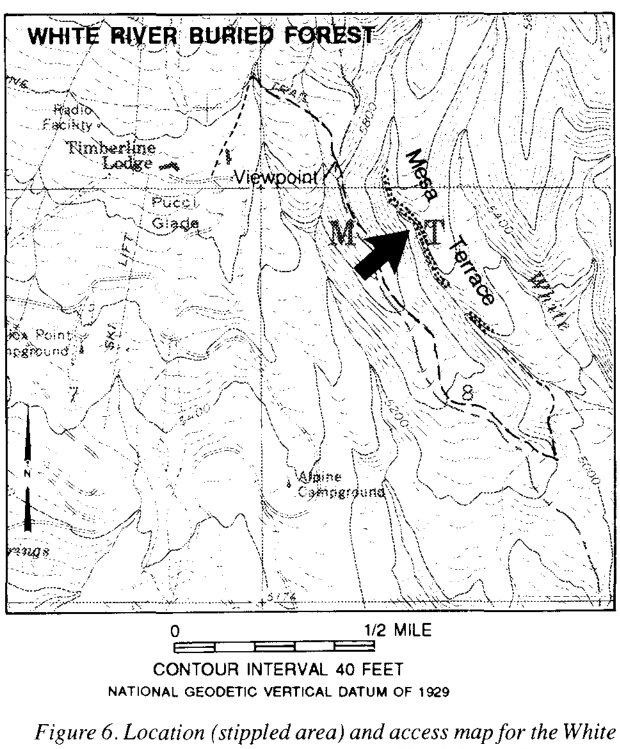

Figure 6. Location (stippled area) and access map for the White River buried forest. Base is from Mount Hood South 7½-minute quadrangle.

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

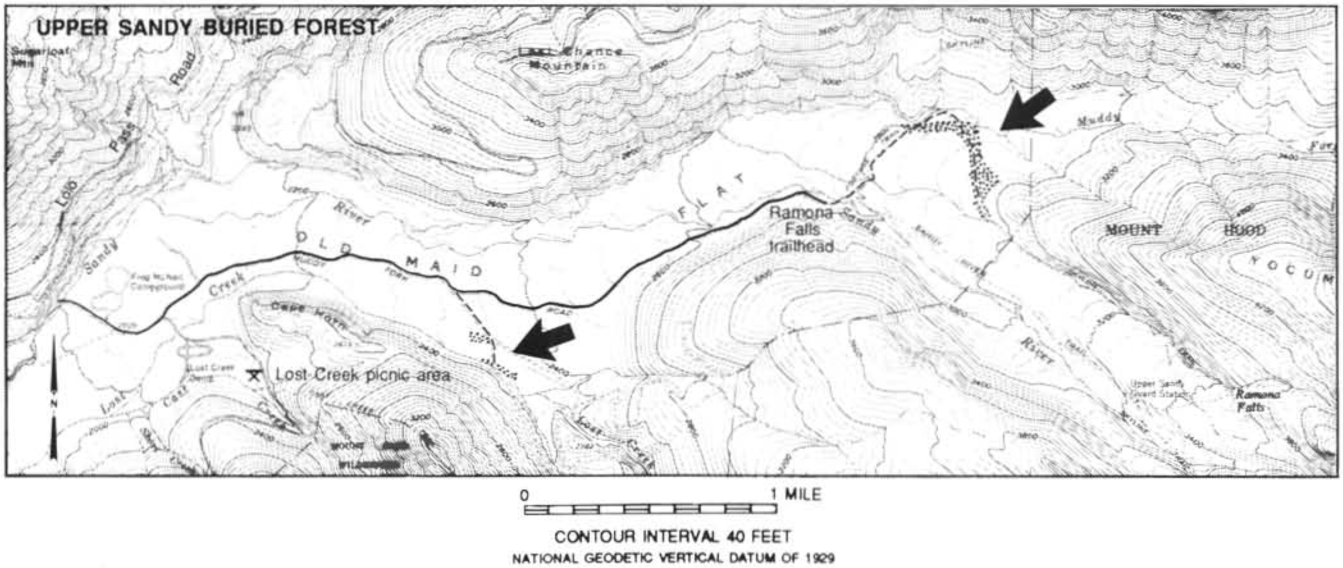

Figure 7. Location (stippled areas) and access map for the Upper Sandy buried forest. Base is from Bull Run Lake 7½-minute quadrangle.

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.

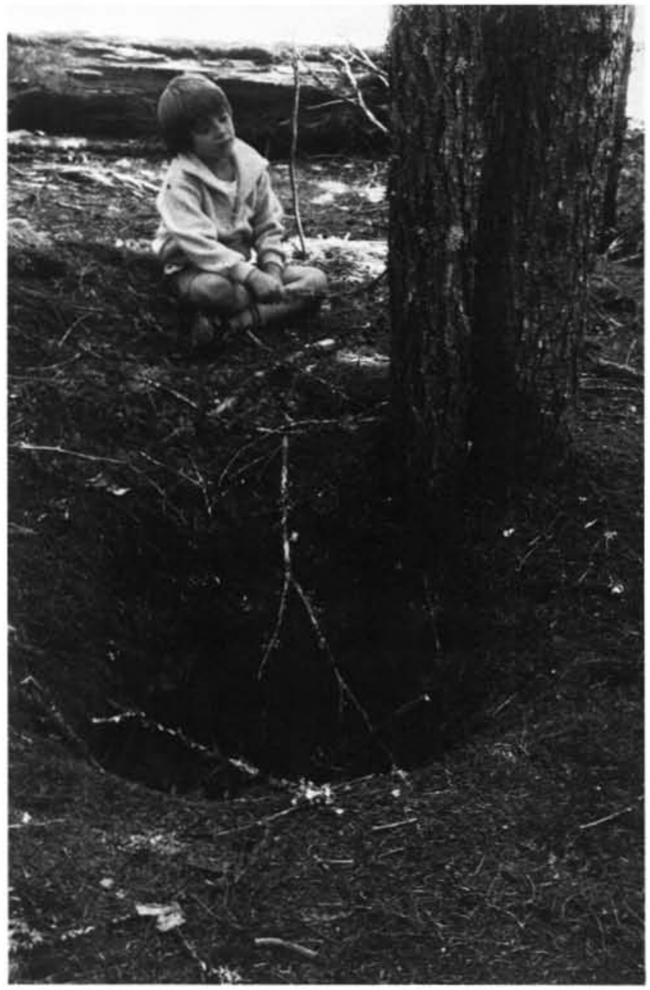

Figure 9. Typical example of a tree well, this one about 3 ft across and 4 ft deep, located near the Lost Creek picnic area.

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

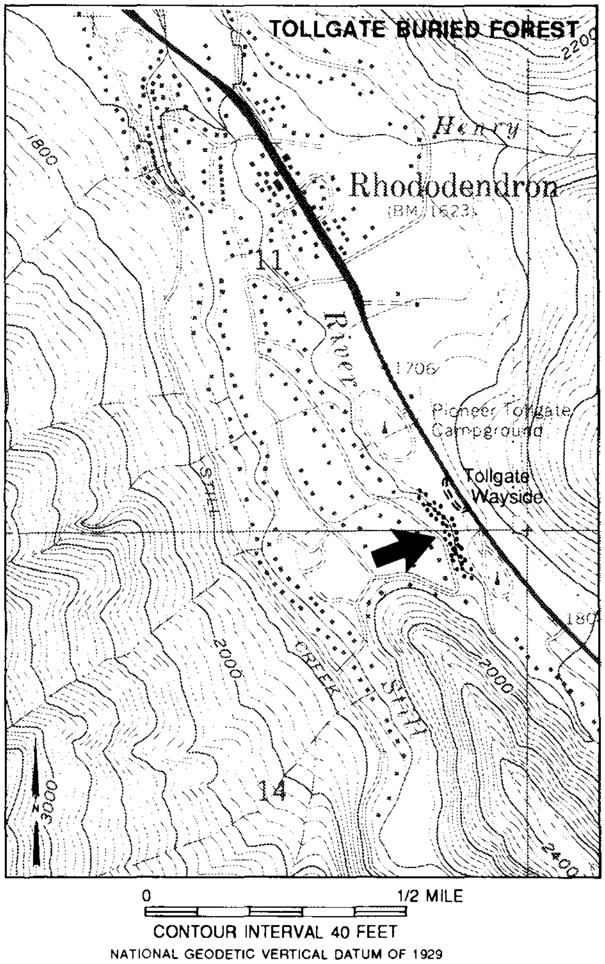

Figure 10. Location (stippled area) and access map for the Tollgate buried forest. Base is from Rhododendron 7½-minute quadrangle.

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

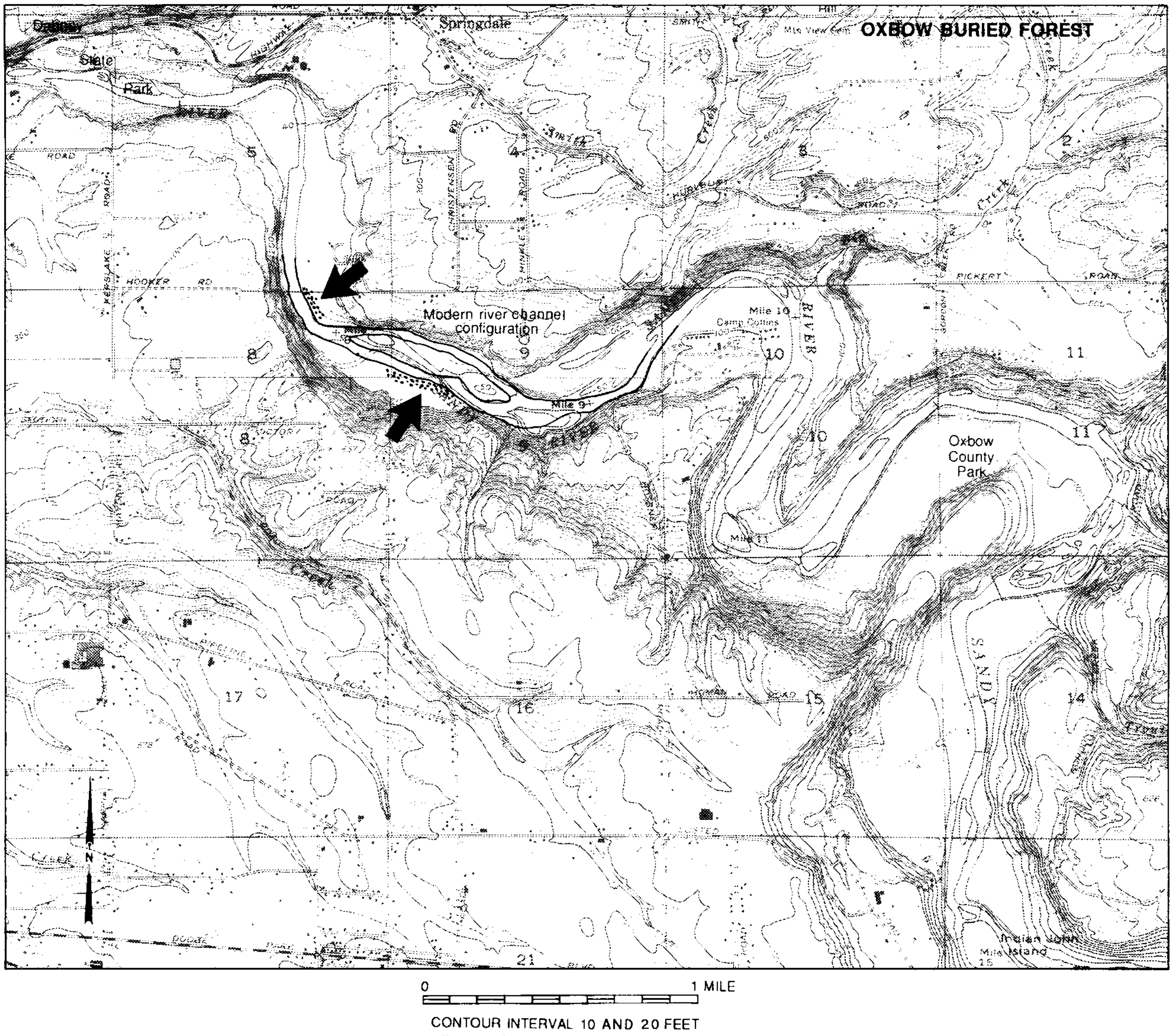

Figure 11. Location (stippled areas) map for the Oxbow buried forest. Note that the configuration of the present river channel is very different from that shown on available map. Base is from Washougal and Sandy 7½-minute quadrangles.

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.

REFERENCES CITED

Cameron, K.A., and Pringle, P.T., 1986, Post-glacial lahars of the Sandy River basin, Mount Hood, Oregon: Northwest Science, v. 60, no. 4, p. 225-237.

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

———1987, A detailed chronology of the most recent major eruptive period at Mount Hood, Oregon: Geological Society of America Bulletin, v. 99, no. 6, p. 845-851.

Crandell, D.R., 1980, Recent eruptive history of Mount Hood, Oregon, and potential hazards from future eruptions: U.S. Geological Survey Bulletin 1492, 81 p.

Franklin, J.F., Cromack, K., Denison, W., McKee, A., Maser, C., Sedell, J., Swanson, F., and Juday, G., 1981, Ecological characteristics of old-growth Douglas-fir forests: Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-118, 48 p.

Hodge, E.T., 1931, Stadter buried forest: Mazama, v. 13, no. 12, p. 82-86.

Lawrence, D.B., 1948, Mount Hood's latest eruption and glacier advances: Mazama, v. 30, no. 13, p. 22-29.

Lawrence, D.B., and Lawrence, E.G., 1959, Radiocarbon dating of some events on Mount Hood and Mount St. Helens: Mazama, v. 41, no. 13, p. 10-18.

Willamette Kayak and Canoe Club, 1986, Soggy sneakers: Guide to Oregon rivers, second edition: Corvallis, Oreg., Willamette Kayak and Canoe Club, 207 p. □

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. □

(**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.

Stanley, G.D., Jr., and Beauvais, L., 1990, Middle Jurassic corals from the Wallowa terrane, west-central Idaho: Journal of Paleontology, v. 64, p. 352-362.

Vallier, T.L., and Brooks, H.C., 1986, Paleozoic and Mesozoic faunas of the Blue Mountains Province: A review of their geologic implications and comments on papers in the volume, *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. 1-6.

Vallier, T.L., and Engebretson, D.C., 1984, The Blue Mountains island arc of Oregon, Idaho, and Washington: An allochthonous coherent terrane from the ancestral western Pacific Ocean?, *in* Howell, D.G., Jones, D.L., Cox, A., and Nur, A., eds., Proceedings of the Circum-Pacific Terrane Conference: Stanford University Publications in Geological Sciences, v. 18, p. 197-199.

White, D.L., and Vallier, T.L., in preparation, Geologic evolution of the Pittsburg Landing area, Snake River Canyon, Oregon and Washington: U.S. Geological Survey Professional Paper 1438.

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

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Baboon Creek Chemstar Lime, Inc.	T. 19 S. R. 38 E.	Limestone	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
Grant 1990	Prairie Diggings Western Gold Exploration and Mining Co.	T. 13 S. R. 32 E.	Gold	Expl
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
Lake 1988	Quartz Mountain Wavecrest Resources, Inc.	T. 37 S. R. 16 E.	Gold	Expl
Malheur 1990	Katey Claims Asarco, Inc.	Tps. 24-25 S. Rs. 44-46 E.	Gold	Expl
Malheur 1989	Hope Butte Chevron Resources Company	T. 17 S. R. 43 E.	Gold	Expl, com
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
Malheur 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E.	Gold	App
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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.	Bentonite	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. □

Slide sets on geologic hazards offered

The National Geophysical Data Center is currently offering 18 affordable 35-mm slide sets about geologic hazards for both technical and nontechnical audiences. Each set consists of 20 slides (mostly color), background material and descriptions of effects for the depicted hazards, and upon request, for teachers, a free set of 20 multiple-choice questions and answers. The price for each set is $25 plus a $10 handling charge per order.

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