

OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 56, NUMBER 6

NOVEMBER 1994



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(ISSN 0164-3304)

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

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Cover photo

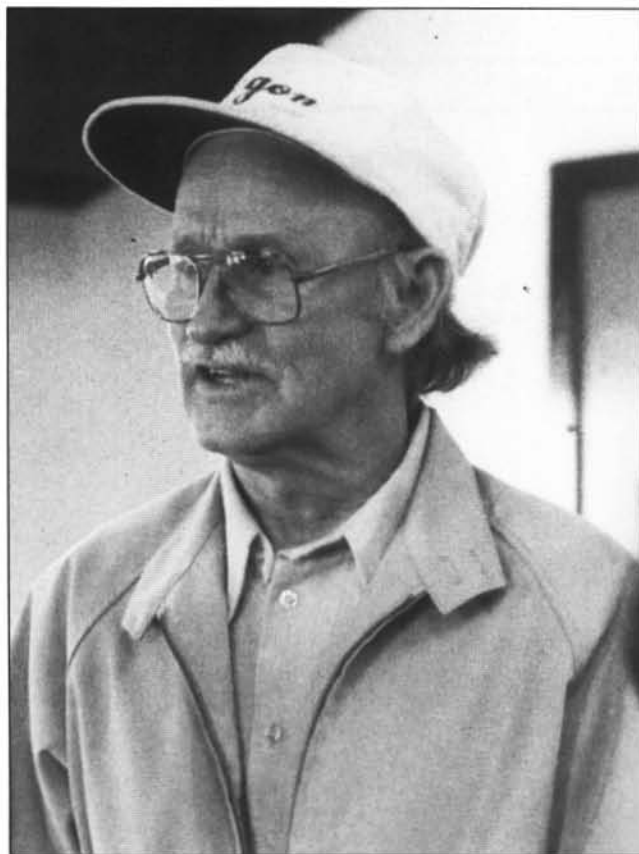
Fort Rock in Lake County, is a spectacular example of the many volcanic features of Oregon that Norm Peterson, whose death we mourn, brought closer to our readers.

Fort Rock is the eroded remnant of a so-called maar, created in early Pleistocene time (about a million years ago) through gigantic steam explosions that occurred when rising magma reached the land surface and encountered large amounts of surface water—a lake, perhaps.

Norm Peterson (with Ed Groh) described such maars in an article in the May 1963 issue of what was then still the *Ore Bin*.

In memoriam: Norm Peterson

Norman V. Peterson, District Geologist for 25 years at the Grants Pass field office of the Oregon Department of Geology and Mineral Industries, died on October 26, 1994, at his home in Grants Pass. It was one day before his 74th birthday.



Norman V. Peterson, during a visit to the DOGAMI field office in Grants Pass in 1990.

Norm retired from his duties in December 1982. During his years with the Department he participated in geologic studies covering most of Oregon and authored or coauthored over 50 articles, papers, and books on both technical and general-interest subjects.

He conducted commodity studies of uranium, limestone, diatomite, pumice, perlite, volcanic cinders, and geothermal resources; worked on numerous county studies including Lake, Klamath, Deschutes, Josephine, and Douglas Counties; assisted with geologic mapping of the Crescent and Jordan Valley 1° by 2° quadrangles; participated in the wilderness mineral evaluations in Harney and Malheur Counties; and helped author nuclear power plant siting and volcanic hazards studies.

He introduced many of our readers to the volcanic wonders of Oregon by his popular articles and field trip guides about such places as Hole-in-the-Ground, Diamond Craters, Cove Palisades State Park, Fort Rock, Newberry volcano, and Crack-in-the-Ground. He was coeditor (with Ed Groh) of the *Lunar Geologic Field Conference Guidebook* (1965), which focused on Oregon's volcanic features at the time when some of them were studied and used as training ground for landing on the Moon.

Beyond his professional accomplishments in his service to the people of Oregon, Norm will be remembered by all who ever met him for his cheerful friendliness. Those who worked with him admired his unflagging willingness to work long hours and endure hardships for the work he loved. □

The geology and mineralization of the President Mine, Bohemia mining district, Lane County, Oregon

by Robert E. Streiff, Geologist, Echo Bay Minerals Company, McCoy Mine, P.O. Box 1658, Battle Mountain, Nevada 89820

ABSTRACT

The geology and mineralization of the President Mine in the Bohemia mining district of Oregon are characteristic of a complex volcanogenic epithermal deposit. Three major phases of faulting and five stages of mineralization have been identified.

Early stages containing quartz with chalcopyrite, galena, sphalerite, and pyrite are typical of the Bohemia district mineralization but do not contain significant gold mineralization. Economic gold mineralization is intimately associated with pyrite in a later dolomite-stibnite and quartz-sulfide event. Vein sediments are associated with the dolomite mineralization. A hiatus in mineralization, followed by renewed right-lateral faulting, separates earlier quartz-sulfide from later dolomite-stibnite mineralization. Postmineral faulting and oxidation have further complicated the deposit.

The gap in mineralization, the radical change in mineralogy, and the anastomosing form of later veining indicate that earlier quartz-sulfide veining represents a deeper epithermal system than later dolomite-stibnite mineralization. This implies rapid erosion of the Bohemia volcanic complex between earlier and later mineralization events.

INTRODUCTION

The President Mine is at the southern edge of the Bohemia mining district, Lane County, Oregon (Figure 1). Although claims are located on several parallel veins, the focus of activity has been on the President or El Capitan vein. The principle workings are on the Coolidge claim, at an elevation of about 1,190 m (3,900 ft). The vein crops out for more than 1,220 m (4,000 ft) on the south-facing slope in the Saint Peter Creek canyon, mainly in sec. 23, T. 23 S., R. 1 E. The canyon is very steep, and outcrops are numerous.

Literature on the President Mine is lacking due to a relatively late development history. Recent mapping, sampling, and development at the mine have afforded the opportunity to study the deposit in some detail.

HISTORY

The first claims located on the President vein were filed by A.P. Churchill in 1898. Churchill trenched the President and parallel veins, drove several short adits, and attempted to finance development of the claims by issuing stock. Ore was found on the Cleveland claim (later to become the Coolidge claim), but it was not developed by Churchill (W.B. Patten, personal communication, 1979).

The claims were taken over on a labor lien in 1926 by William B. Patten. Patten began developing ore on the Coolidge claim and, by 1940, was operating a two-stamp mill on ore from the upper Coolidge adit, which was by then about 30 m (100 ft) deep. Patten's two-stamp mill was destroyed by an avalanche in 1946. The lower Coolidge adit was driven about 90 m (300 ft) and encountered good ore in the three shoots. Based upon showings observed on the claims, Patten entered into partnership with H.L. Lilegren in 1950 to build a road to the claims. Reconstruction of 4.8 km (3 mi) of road and construction of 9.7 km (6 mi) of new road were accomplished before the partnership fell into litigation and was dissolved in 1956 (W.B. Patten, personal communication, 1979).

Patten leased the claims to Lane Minerals, Inc., in 1957. Lane Minerals completed the road to the Coolidge adits and did considerable surface trenching and some underground development work. The company shipped about 20 tons averaging 57.2 grams/ton (g/ton) (1.67 oz/ton) gold and 48.0 g/ton (1.40 oz/ton) silver to the

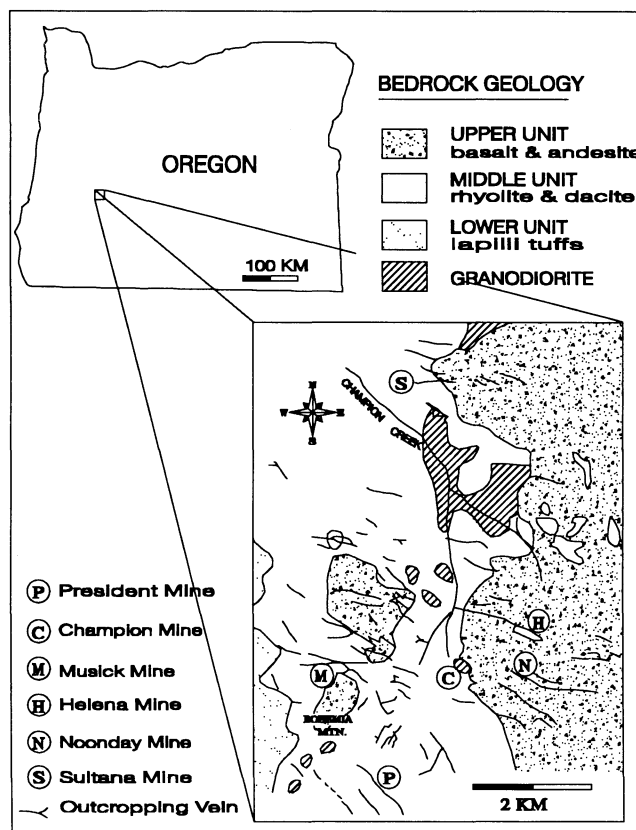


Figure 1. Location map of the Bohemia mining district. Modified from Schieber and Katsura (1986).

Tacoma, Washington, smelter in 1959. The price of gold, however, prevented serious development (H.E.L. Barton, personal communication, 1977).

Lane Minerals changed its name to Bohemia Minerals, Inc., in the mid-1960s. The claims were later deeded to H.E.L. Barton, a geologist, for services he provided Lane and Bohemia Minerals (H.E.L. Barton, personal communication, 1977).

This author purchased the original three claims from Barton in 1977. These claims were leased to James W. Edgar in 1979, and the lease was terminated 10 years later. A mapping and sampling program is in progress at the time this paper is being written.

Total production value from the mine has not exceeded \$5,000. All production has come from the upper and lower Coolidge adits.

REGIONAL GEOLOGY

The Cascade Range is the product of arc volcanism that has been active since Eocene times (McBirney and others, 1974; Power, 1985). In Oregon, the Cascade Range has been subdivided into two belts of volcanic rocks, the Western Cascades of Eocene to Pliocene age and the High Cascades of Pliocene to Holocene age (Peck and others, 1964; Priest and others, 1983). The Bohemia mining district lies within the Tertiary Western Cascades province of Oregon.

The Western Cascades consist of flows, pyroclastic rocks, and volcanoclastic sediments that were deposited from numerous volcanic

centers (Peck and others, 1964). Minor folding of the Western Cascades, along northeast-trending fold axes, occurred during several periods in late Eocene and late Miocene time (Peck and others, 1964). The High Cascades, consisting mainly of basaltic to andesitic flows and of stratovolcano complexes, fill a north-south-trending graben that developed in older volcanic rocks (Priest and others, 1983).

An active volcanic center existed in the Bohemia area during the Oligocene to early Miocene (Peck, 1960; Lutton, 1962). Interstratified flows and tuffs of basaltic to rhyolitic composition have been mapped and divided into three units (Figure 1) by Lutton (1962). The lower unit consists of over 300 m (990 ft) of massive dacitic to rhyolitic lapilli tuffs with locally intercalated tuffaceous sandstones and lacustrine shales. The intermediate unit (approximately 450 m [1,485 ft] thick) is characterized by dacites and rhyolitic dome complexes with onlapping flows and pyroclastics that fill erosional paleotopographic features in the massive tuffs of the lower unit. The upper unit (approximately 250 m [825 ft] thick) consists predominantly of basalt and andesite flows with minor dacite flows and intercalated lapilli tuffs. The granodioritic Champion stock and related plugs and dikes crosscut all volcanic units (Figure 1). Power and others (1981) determined an age of 21.7 m.y. for the Champion stock. Crosscutting relationships show that the epithermal veins of the Bohemia district postdate the Champion stock and are therefore younger than the associated volcanic and intrusive rocks.

LOCAL SURFACE GEOLOGY

The geology in the immediate vicinity of the claims is poorly understood. Lutton (1962) assigned the volcanic rocks in the claim group to the middle unit, which is composed of rhyolitic and dacitic dome complexes with onlapping flows and intercalated pyroclastic rocks. Numerous andesitic and basaltic dikes invade these volcanic rocks and are presumed to be feeders to the upper unit. A porphyritic dacite body crops out over a large area about 60 m (200 ft) or more southeast of the main adits on the Lincoln claim and parts of the Coolidge and Washington claims. Taber (1949) identifies this dacite body as a large intrusive. However, Lutton (1962) mapped the dacite as a large flow that crops out as far as Rock Creek canyon about 3.2 km (2 mi) to the southwest. The main President vein cuts through this dacite flow.

Several dikes occur nearly parallel to the President vein at the Coolidge adit. A lacustrine tuff is exposed in the hanging wall of the upper Coolidge adit, while the footwall is andesite. All volcanic rocks, including the dacite and local dikes, display pervasive propylitic alteration.

STRUCTURE

The President vein occupies a fault of unknown total displacement. This is most apparent at the upper Coolidge adit portal, where the hanging wall of the vein is a lacustrine tuff, and the footwall is a series of labradorite andesite flows. Presumably the footwall tuffs have been removed by erosion. A right-lateral component of movement is indicated by underground mapping.

The fault strikes N. 55°–60° W. and dips from 80° to vertical. The main ore zone on the Coolidge claim is located where the fault turns from N. 55° W. to N. 25° W.

Underground mapping indicates at least three periods of minor right-lateral movement, which has displaced earlier quartz-sulfide ore lenses and later carbonate-stibnite zones. The total lateral displacement is at least 15 m (50 ft). During right-lateral movement, tension fractures developed along a N. 25° W. direction and dilated, allowing ore deposition to occur in the Bughole drift (Figure 2). These tension fractures continued to dilate, keeping the Bughole portion of the vein open over an extended period of time.

Three phases of faulting are recognized (Figure 3). Phase 1 opened the fault so that lenses of quartz sulfide (stage II and III minerals) were deposited. These lenses were then offset approximately 3 to 5 m (10–15 ft) by phase 2 faulting, leaving a trail of

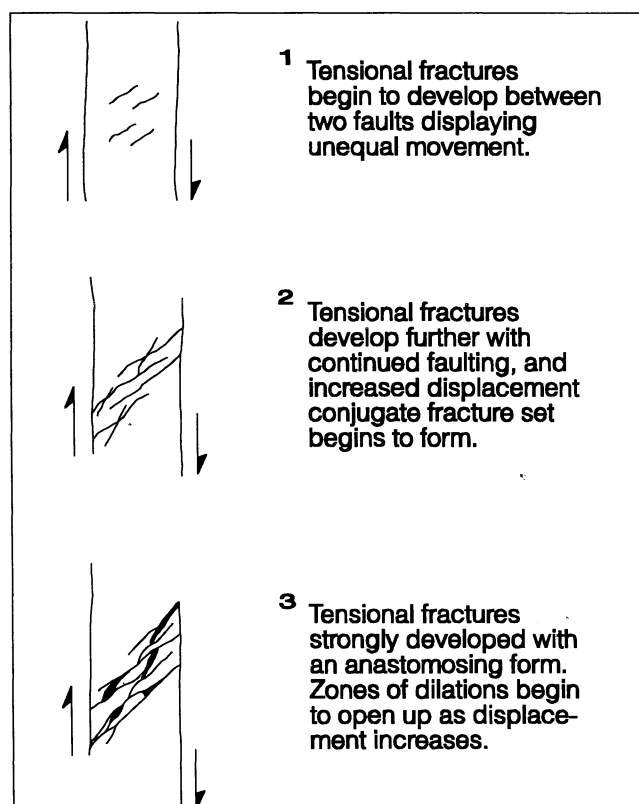


Figure 2. Model for development of tensional fractures at the President Mine (plan view, no scale).

breccia clasts between lenses that were incorporated into carbonate (stage IV) veining. Thus, the quartz-sulfide lenses appear staggered from hanging wall to footwall to hanging wall along the strike of the vein, with a more continuous carbonate vein dividing the quartz-sulfide lenses.

A third, postmineral faulting event (phase 3) further displaced the quartz-sulfide lenses and, to a lesser extent, the carbonate-stibnite veining. This third phase of faulting did not follow previous dilations in the Bughole area but took a new course, resulting in a split in veining at the Bughole drift. The Mattox drift follows this postmineral fault for about 21 m (70 ft), but no significant values were encountered. This late faulting is characterized by moderate brecciation, some gouge formation, and heavy postmineral oxidation. The total lateral displacement of the last two faulting events is about 7.5 to 9 m (25–30 ft).

McChesney (1987) noted right-lateral strike-slip faulting on the Sultana vein of the Miller Group in the northern portion of the Bohemia mining district. Two phases of faulting were observed. The first phase was subsequently mineralized by a gold-sulfide-quartz filling. This veining was then offset by a postmineral fault that paralleled the vein and locally offset it. McChesney proposed that this type of offset was a result of regional wrench faulting. The fact that right-lateral strike-slip faulting has been noted on the opposite side of the district at the President Mine lends credibility to this hypothesis. Gold mineralization at the President Mine is very different, however.

ALTERATION

Alteration types found at the President Mine include pervasive propylitic, sericitic, and argillic. Earlier propylitic alteration is overprinted by later sericitic and argillic assemblages.

The volcanic rocks show pervasive propylitic alteration throughout the Bohemia district. Locally, this alteration consists of chlorite

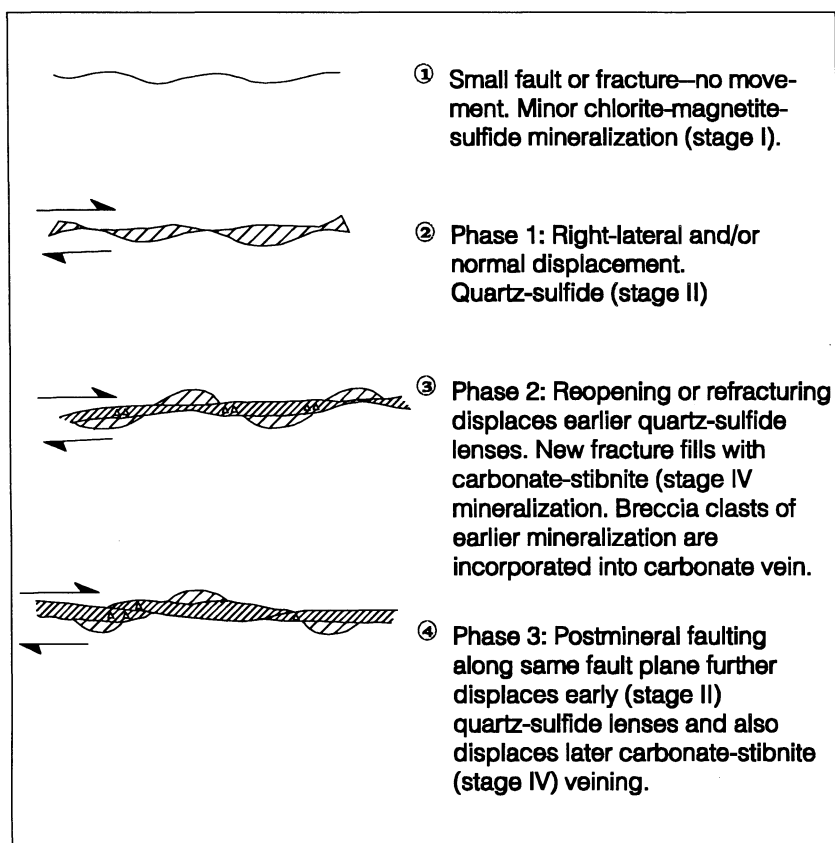


Figure 3. Faulting phases at the President Mine (plan view, no scale).

± epidote ± calcite + magnetite. Chlorite is pervasive and is found both as replacement of mafic minerals and within the groundmass. Epidote appears to be slightly later and is often structurally controlled. Calcite is often found both in the matrix and replacing plagioclase. Magnetite is a minor constituent of the various volcanic rocks locally.

The porphyritic dacite flow that crops out southeast of the main Coolidge adits shows pervasive sericitic alteration over a large area. The rock generally appears bleached from sericite replacement of both mafic minerals and groundmass. Minor silicification with disseminated pyrite is locally present. The dacite hosts a swarm of phenocryst overgrowth veinlets similar to those at Round Mountain, Nevada, which rarely exceed 5 mm in width. No disseminated-type precious metal mineralization has been identified.

Sericitic alteration forms 0.3- to 3-m (1–10 ft) envelopes in all rock types around the President vein. This alteration consists of sericite, pyrite, and local silicification. Sericite replaces both mafic minerals and groundmass. Pyrite occurs as 1-mm cubes disseminated in the volcanic rocks around the vein. Silicification often occurs as 5- to 20-mm envelopes around quartz veining. Sericitic alteration appears to be related to quartz-sulfide mineralization of stages II and III.

Carbonate minerals occur in an alteration envelope from 1.5 to 4.5 m (5–15 ft) around the President vein. Carbonate replaces both plagioclase and groundmass and is most intensely developed around stage IV dolomite veining. Silicified areas do not contain carbonate.

Argillic alteration occurs as an outer alteration envelope around sericitic zones. At the President Mine, argillic alteration mainly has kaolin replacing feldspar phenocrysts. Groundmass can look slightly bleached in some locations but often is fresh looking in hand specimens. Argillic alteration at the President Mine is volumetrically unimportant compared to sericitic alteration.

VEIN MINERALOGY

Five stages of mineralization have been identified in the President vein system. These five stages have been classified based on crosscutting relationships, brecciation, and colloform banding. Oxidation followed these mineralization events.

Stage I

Chlorite, epidote, magnetite, quartz, and carbonate characterize the earliest stage of mineralization at the President Mine. This mineralization is part of the district-wide alteration of the host volcanic rocks and is related to contact metamorphism and emplacement of the Champion stock (Katsura, 1988). Locally, in addition to pervasive propylitic alteration, small veinlets and crackle breccias cemented by quartz-chlorite can be found in the President vein. These veinlets occur in breccia clasts incorporated into the mineralization of stages II, III, and IV.

Stage II

The beginning of stage II quartz-sulfide mineralization is marked by a faulting and brecciation event (phase 1 faulting) that opened the President fault, allowing open-space filling by quartz and various sulfides in swells of the fault. The quartz is coarsely crystalline and exhibits crustification and colloform banding. The quartz contains various amounts of pyrite (1–2 percent), sphalerite (<1 to 5 percent), chalcopyrite (<1 to 2 percent) and galena (2–6 percent). Crustification banding suggests that sphalerite was dominant during the early stages of stage II, while chalcopyrite and especially galena became dominant later. Pyrite is ubiquitous.

Stage III

The transition from the end of stage II to the beginning of stage III is not clear, but it is thought to be marked by the first of two brecciation events. Stage III is similar to stage II except for specular hematite, which gives the quartz that cements breccia a purple hue. Galena and chalcopyrite dominate this phase, while sphalerite is subordinate.

Both stages II and III are similar to the typical, district-wide quartz-sulfide mineralization found on many mine dumps in the Bohemia area. However, galena is more abundant at the President Mine, similar to the Musick Mine (Callahan and Buddington, 1938). The quartz-sulfide mineralization at the President Mine occurs in discrete lenses rather than in continuous veins. Precious metal values in stages II and III are low; typically less than 0.7 g/ton (0.02 oz/ton) of gold and 0.3 g/ton (0.01 oz/ton) of silver.

Stage IV

Stage IV is marked by both a large brecciation event (phase 2 faulting) and a radical change in vein mineralogy. Presumably, a long time interval separated stage III and stage IV mineralization. The large brecciation event that marks the beginning of stage IV mineralization is presumably the result of phase 2 faulting, which split and offset earlier quartz-sulfide lenses (Figure 3). A trail of quartz-sulfide breccia clasts between sulfide lenses is incorporated into stage IV mineralization. Stage IV mineralization is dominated by dolomite that hosts stibnite, galena, pyrite, and quartz containing auriferous pyrite plus minor chalcopyrite, galena, and sphalerite.

A scanning electron microprobe of the dolomite gangue indicates a high-iron, high-manganese dolomite. The iron content is not high enough to classify the dolomite as ankerite. Differences in the degree of weathering suggest that earlier dolomite has a higher iron content than dolomite deposited later in sequence.

Galena is often found as coarse cubes at the wall-rock contact with dolomite. It is usually not found hosted within the dolomite away from wall-rock contacts and represents the earliest sulfide of stage IV mineralization.

Stibnite occurs as spectacular radiating clusters of needlelike crystals up to 20 cm (8 in.) long, hosted by the dolomite gangue. The stibnite occurs in elongate pods or lenses with nearly vertical rake. Locally, these pods may assay as high as 40 percent antimony. Galena is often along the wall-rock contacts of the stibnite lenses.

Following the initial dolomite, stibnite, and galena deposition, repeated brecciation occurred, followed by dolomite and then quartz-sulfide-gold infill mineralization. The dolomite and quartz consist of paired sequences of early, off-white-colored dolomite bands that are followed by clear quartz in thin bands which host sulfides. These paired sequences are repeated several times but are complicated by intervening brecciation so that later paired bands of dolomite and quartz crosscut earlier bands.

The quartz often occurs as casts or molds of calcite scalenohedra within the dolomite, yet no calcite is present. This suggests that dolomite may have replaced earlier calcite so that the only indications of calcite remaining are molds of the calcite crystals by quartz. Some casts indicate crystals up to 5 cm (2 in.) long.

Thin sections cut across the paired bands of dolomite and quartz show that the dolomite does not contain gold. Assays of dolomite without quartz indicate a low gold content of less than 1.0 g/ton (0.03 oz/ton) of gold.

However, the thin sections reveal electrum in the quartz bands of the paired sequence. The electrum occurs on the faces of pyrite cubes or as apparent exsolution blebs within the pyrite. Chalcopyrite, galena, and sphalerite are also present in subordinate amounts. Portions of the President vein that contain paired sequences of dolomite and quartz sulfides typically assay from 17 g/ton (0.50 oz/ton) to 86 g/ton (2.50 oz/ton) gold. Silver occurs in a roughly 1:1 ratio with the gold.

Brecciation and recementing of dolomite was common during phase 3 faulting. At least three distinct brecciation events are recognized. Associated with these brecciation events are vein sediments that occupy vugs in the dolomite. These sediments exhibit typical sedimentary features, such as grading, slump structures, and deformation by larger pebbles. The bedding is perfectly horizontal, indicating no tilting of the vein since sediment deposition.

The sediments are composed chiefly of very fine grained dolomite and silica. Small particles of pyrite are sometimes found in certain beds, as well as stibnite and galena. These sediments indicate areas of relatively calm fluid flow within the President vein during the time they were deposited (Schieber and Katsura, 1986). They are roughly analogous to clastic dikes. These sediments plus the nature of the breccia suggest that the breccia is hydrothermal rather than mechanical in origin. However, the breccia could also be a result of continued fault movement and reopening (widening) of the tension fractures. Vein sediments have been found as breccia clasts cemented by later dolomite.

Schieber and Katsura (1986) discussed vein sediments from the Bohemia mining district in some detail. Figure 3 in their article shows a sample from the lower Coolidge adit of the President Mine. They interpreted these sedimentary features as sedimentary accumulations due to calm fluid flow adjacent to areas of boiling. Banding is due to episodic flow from episodic eruptions or boiling of fluids. Thus, most breccias formed during vein sedimentation are the result of hydrothermal brecciation. The fact that vein sediments occur only during the carbonate stage IV period suggests that boiling occurred during stage IV.

Stage V

Following the quartz-pyrite-gold phase were minor refracturing and stage V calcite mineralization. The calcite occurs as coarsely crystalline scalenohedra that line vugs and open fractures within the

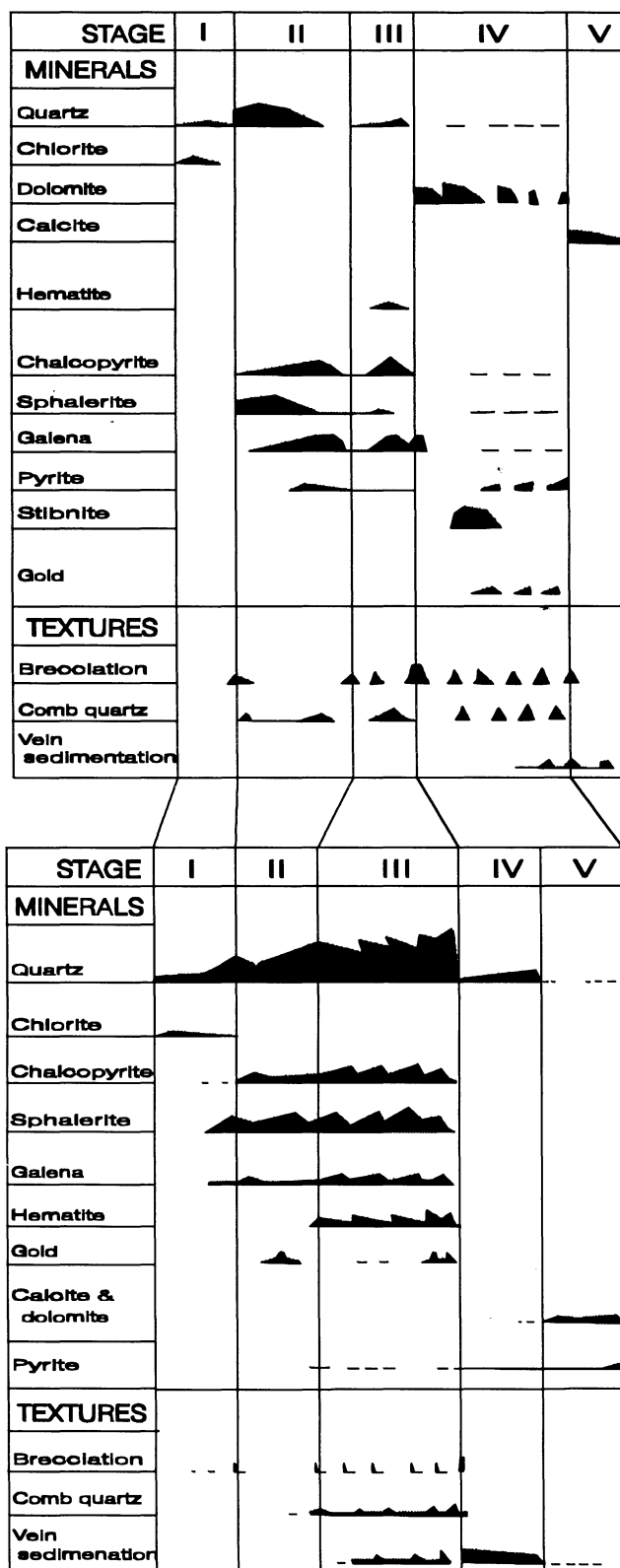


Figure 4. Generalized paragenetic sequence of minerals, brecciation events, and vein sediments at the President Mine (above) and the Champion Mine (below) and the correlation between them. The height of blackened areas indicates relative abundance of minerals or features. Modified from Schieber and Katsura (1986).

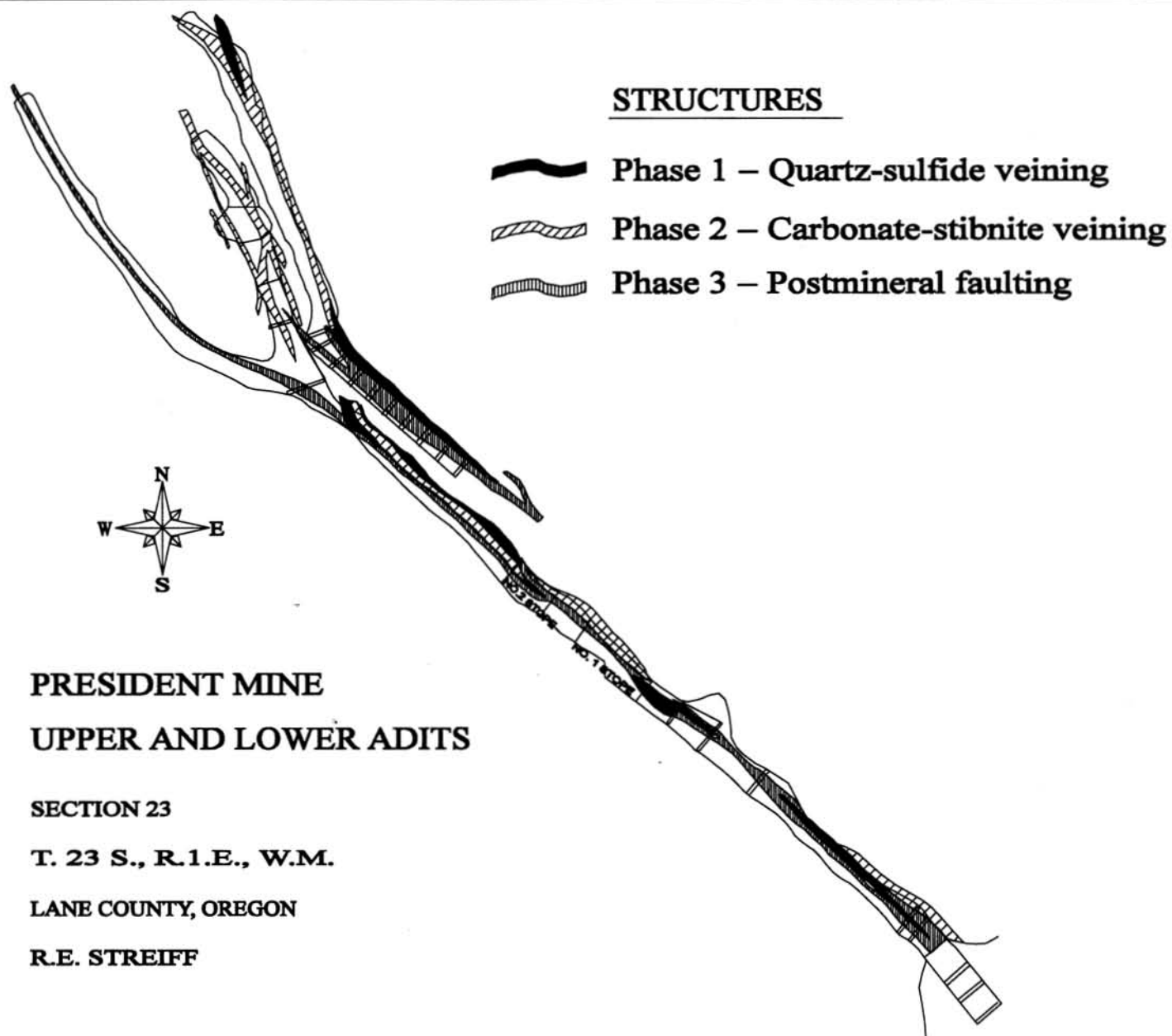


Figure 5. Geologic map of the upper and lower Coolidge adits at the President Mine (plan view, no scale).

vein. Several incompletely filled areas of the dolomite veining contain calcite scalenohedral crystals up to 5 cm (2 in.) long. Locally, the calcite is sometimes brown or black in color. Some vugs are up to 45 cm (18 in.) wide, 6 m (20 ft) long, and 9 m (30 ft) high and are faced with calcite crystals. This late calcite contains no sulfides and is low in gold and silver.

Oxidation

Oxidation and weathering of the deposit occurred following the calcite stage. The carbonates were particularly susceptible to weathering and are responsible for much of the residual limonite and manganese minerals. Sulfides were mainly leached away, so that the net result was a slight upgrading of gold in the oxidized zone and a liberation of fine gold from encapsulation. Some of this gold migrated downward in the vein through the numerous open spaces provided by weathering and already present in the vein, similar to placer gold (Lutton 1962). Pockets of residual fine gold (placer-type) have been found in the lower oxidized zone, particularly in the bottom of large, open cavities.

Fine gold liberated during oxidation may also have been moved chemically, probably by manganese, to the lower oxidized zone and recrystallized on the surface of goethite pseudomorphs in coarser leaves and wires. The importance of this chemical enrichment in the deposit has probably been overestimated, however.

Erosion has been rapid in the Saint Peter Creek canyon, which is narrow with very steep walls. Therefore, the level of oxidation is relatively shallow (60 m [200 ft]), since the outcrop is stripped off by erosion shortly after oxidation.

Cerussite is not uncommon in the oxidized zone, occurring as small greenish-yellow crystals. Stibiconite can sometimes be identified when pseudomorphed after stibnite. Some perfectly translucent, coarsely crystalline quartz lines limonite-stained vugs and boxwork and is probably a late supergene remobilization of earlier quartz of stages II and III existing in the vein. In some cases, this quartz can clearly be seen postdating initial oxidation of the host vein rock.

Figure 4 shows the generalized paragenetic sequences of the Champion and President Mines and the correlation between them. Overall, the two mines compare reasonably well. Most of the stages of the Champion Mine are represented in the President, although the volume and thus importance of each stage vary considerably.

DISCUSSION

Crustification, colloform banding, and anomalous antimony, arsenic, and mercury geochemistry at the President Mine are characteristic of epithermal deposits. Epithermal characteristics in the Bohemia district have been noted by Lutton (1962), McChesney (1987), and Katsura (1988).

The President epithermal vein system (Figure 5) occupies a fault with at least 15 m (50 ft) of displacement. Fault movement was episodic. Rake of the gold ore zones and lenses of stibnite suggest normal dip-slip with a small component of right-lateral movement, but the actual displacement direction and amount are uncertain. Mapping indicates right-lateral displacement, however.

The typical Bohemia-style quartz-sulfide mineralization (stages II and III) occurs in discontinuous lenses along a single fault plane. The quartz-sulfide mineralization does not host significant precious metal mineralization. Alteration is dominantly sericitic. These features suggest that stages II and III represent a deeper portion of an epithermal vein system, below the zone of precious metal mineralization. The influx of stage III hematite implies a decrease in available sulfur as the quartz-sulfide stages waned. This increase in hematite over time is opposite of the Champion Mine (Katsura, 1988) but similar to the Sultana vein (McChesney, 1987).

The mineralization and overall morphology of stage IV are radically different from previous stages. Unlike previous mineralization, stage IV veining is both anastomosing and bifurcating. Dolomite is the dominant gangue mineral. Stibnite is a significant

sulfide. Electrum-bearing pyrite is the major gold occurrence at the President and is contained within stage IV only. All of these features suggest that stage IV is an upper level epithermal event, while stages II and III represent deep epithermal mineralization below the precious metals horizon.

This elevational difference can be explained if one assumes a hiatus between stages III and IV. During this hiatus, rapid erosion lowered the land surface considerably. The depositional hiatus was broken by renewed fault movement at the onset of stage IV. Rapid erosion of the Bohemia volcanic complex would also explain the increase in anomalous antimony, arsenic, and mercury noted at the Champion (Katsura, 1988) and Sultana (McChesney, 1987) Mines over time as well as at the President Mine. However, changes in the overall chemistry of the evolving system and proximity to the Champion stock probably also impacted the mineralogy of the veins. A collapse of the Bohemia hydrothermal system with age probably contributed significantly to the district-wide paragenetic sequence.

ACKNOWLEDGMENTS

I wish to thank Bruce Stewart for permission to publish the data contained within this paper. Special thanks go to Kurt Katsura, who provided hours of discussion and granted permission to use portions of his papers on the Champion Mine.

The manuscript was reviewed by Dorinda Bair and Thomas Hanna. Kris Itza typed the manuscript and the various revisions. Chuck Swisher drafted all of the illustrations.

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Late Cenozoic tectonics and paleogeography of the Salem metropolitan area, central Willamette Valley, Oregon

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ABSTRACT

Logs from 360 water wells, oil wells, and engineering drill holes were used to resolve the structure of the Columbia River Basalt Group and the overlying sequence of valley fill. The regional structure is controlled by the Willamette Valley synclinorium. Short northeast- and northwest-trending faults subdivide this area into the Stayton and northern Willamette structural basins separated by a zone of uplift, the Waldo Hills. Neogene uplift of the Waldo, Salem, and Eola Hills formed a tectonic dam that caused fine-grained alluvial sediments associated with the ancestral Willamette River system to accumulate in the southern Willamette Valley. Overlying these sediments are alluvial and braided-stream gravels deposited as glacial outwash from the North Santiam River drainage. This buried gravel fan traverses the Waldo Hills uplift through a 1-km-wide channel connecting the Stayton and northern Willamette basins. Thickening of the gravel fan indicates that the northern Willamette basin was actively subsiding during its deposition. Magnetostratigraphy combined with fossil pollen data from a 40-m-long drill core tentatively date the fan deposit as Pliocene to middle Pleistocene. Holocene uplift of the Salem-Eola Hills homocline relative to the northern Willamette basin is suggested by a broad convexity in the modern longitudinal profile of the Willamette River. Although the long-term rates of vertical deformation are very low, on the order of 10^{-2} mm/year, the magnitude 5.6 earthquake of 1993 near Scotts Mills demonstrated that intracrustal deformation is continuing.

INTRODUCTION

This paper describes the late Cenozoic structure, depositional history and paleogeography of the Salem metropolitan area. Logs from 360 drill holes were used to resolve the structure of an 800-km² area centered around the city of Salem (Figure 1). The database was assembled by gathering, field-locating, and interpreting logs of water wells, oil wells, and engineering drill holes obtained from the Oregon State Engineer's office, the Oregon Department of Transportation, the U.S. Geological Survey Water Resources Division, and previous studies including Hampton (1963, 1972), Helm and Leonard (1977), and Burns and Caldwell (in preparation). Integrating drill hole data with the surface geology, we constructed structure contour maps and cross sections of the Columbia River Basalt Group and the overlying valley fill. The project also included magnetostratigraphic analyses of two drill cores.

TECTONIC SETTING

The Willamette Valley/Puget Sound lowland is a forearc basin that lies on the convergent margin of the North American continent. This regional downwarp is largely the result of simultaneous late Cenozoic uplift of the Cascade Range and the Coast Range, which enclose the Willamette Valley (Beeson and others, 1989; Priest, 1990; Yeats and others, 1991). West of the valley, tectonic growth throughout the late Cenozoic arched Paleogene continental-shelf sediments into a broad anticlinorium that now forms the present-day Coast Range (Yeats and others, 1991; Niem and others, 1992). In the valley itself, Miocene strata are downwarped to form an elongate structural depression known as the Willamette Valley synclinorium (Beeson and others, 1989; Yeats and others, 1991).

Discontinuous northeast- and northwest-trending faults subdivide the Willamette Valley into a mosaic of fault-bounded blocks

(Yeats and others, 1991). In the north half of the valley, differential subsidence of these blocks created a series of structural subbasins, which include the Portland basin, the Tualatin basin, the northern Willamette basin, and the Stayton basin (Beeson and others, 1989; Yeats and others, 1991; see Figure 1). Linked by the Willamette River system, these bedrock-rimmed basins were progressively infilled with thick sequences of nonmarine strata. In contrast, the southern valley is a single large basin that contains one continuous body of basin fill.

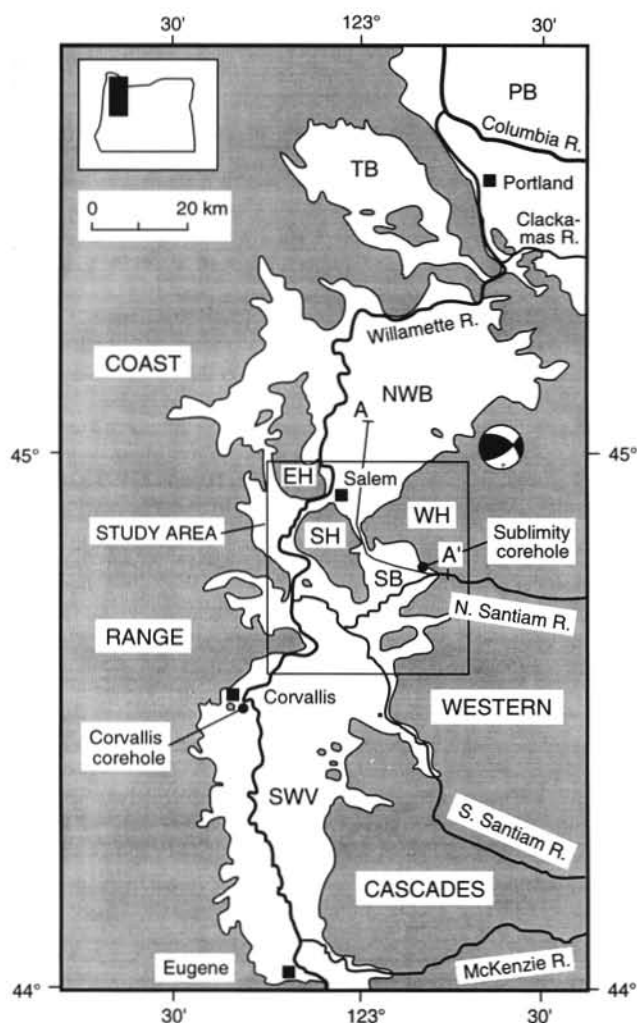


Figure 1. Physiographic map of the Willamette Valley, showing major rivers, the focal mechanism of the magnitude 5.6 Scotts Mills earthquake of 1993 (from Dewey and others, 1994), and the boundaries of the study area. PB = Portland basin, TB = Tualatin basin, NWB = Northern Willamette basin, SB = Stayton basin, EH = Eola Hills, SH = Salem Hills, WH = Waldo Hills, SWV = southern Willamette Valley.

STRATIGRAPHY

Columbia River Basalt Group (middle Miocene)

The Columbia River Basalt Group is a series of flood basalts that originated from vents in northeastern Oregon, southeastern Washington, and western Idaho (Wells and Peck, 1961; Mangan and others, 1986; Beeson and others, 1989). In a massive pulse of magma extrusion, flow units of the Grande Ronde Basalt completely inundated the northern Willamette Valley, extending as far south as Franklin Butte (Beeson and others, 1989). These flows, the first to reach the Salem area, account for the bulk of flood basalt in the Willamette Valley. Thin flows of the Wanapum Basalt traversed the broad surface formed by the Grande Ronde Basalt, filling structural depressions, broad erosional channels, and topographic lows along its margins (Beeson and others, 1985, 1989). Seven potassium-argon dates from Grande Ronde and Wanapum Basalt in the study area cluster between 14.0 ± 0.2 Ma and 15.6 ± 0.8 Ma (Lux, 1982; Walker and Duncan, 1989).

The valley fill

Global climatic change in the Pliocene-Pleistocene led to glaciation of the Cascades and loaded the eastern tributaries of the Willamette River with glacially derived sediments. Glacio-fluvial outwash spilled into the Willamette Valley and migrated across the valley floor as massive, aggrading fans. Three terraces, underlain by the Lacombe, Leffler, and Linn gravels, record the latest pulses of glacio-fluvial sedimentation (McDowell, 1991). The Lacombe and Leffler gravels form west-sloping (0.5° – 1°) terraces, preserved mainly in drainages exiting the Western Cascades, while the youngest glacio-fluvial deposit, the Linn gravels, underlies most of the valley floor (Allison, 1953; Allison and Felts, 1956; Beaulieu and others, 1974; Yeats and others, 1991). Radiocarbon age estimates for the Linn gravels range from $28,480 \pm 1,810$ to $> 40,000$ years B.P. (Glenn, 1965; Balster and Parsons, 1969; Roberts, 1984).

Thick gravel deposits in the subsurface are interpreted to be composites of glacio-fluvial outwash fans and older fluvial deposits predating glaciation (Gannett, 1992). Yeats and others (1991) proposed that the deep gravels in the southern Willamette Valley represent a channel facies of the proto-Willamette River that was buried beneath a sheet of glacial outwash. Most of these gravels, however, coincide with major tributary drainages from the Western Cascades and do not define an ancestral course of the Willamette River (Gannett, 1992). The two largest gravel fans, associated with the Willamette and North Santiam Rivers, extend down the center of the valley, but they also grade laterally into fine-grained sediment (M. Gannett, U.S. Geologic Survey, Water Resources Division, Portland, Oregon, written communication, May 27, 1993) and are, therefore, not part of a continuous channel deposit.

The lower section of the valley fill, known informally to water-well drillers as "the blue clay," consists predominately of fine-grained facies (Trimble, 1963; Hampton, 1972; Helm and Leonard, 1977; Yeats and others, 1991). In the northern Willamette Valley, moderately to poorly lithified siltstone, sandstone, mudstone, and claystone, commonly containing wood, crop out along the banks of the Clackamas and Sandy Rivers. This unit, named the Sandy River Mudstone by Trimble (1963), may correlate with the fine-grained sediments in the southern and central Willamette Valley that have been documented in drill holes near Monroe, Lebanon, Corvallis, and Sublimity (Roberts and Whitehead, 1984; Niem and others, 1987; Yeats and others, 1991).

The depositional environment of the fine-grained facies is not well understood, although both lacustrine and overbank origins have been proposed (Roberts and Whitehead, 1984; Yeats and others, 1991). The widespread existence of fine-grained sediment in the lower section of the valley fill may reflect a period of low sediment output from lower-relief topography in the Miocene.

Lithostratigraphy of the Salem metropolitan area: The valley-fill sequence in the study area compares well with the regional stratigraphy of the Willamette Valley. Drill hole logs show that the valley fill is divided into a lower section and an upper section. The upper section consists chiefly of gravel with varying amounts of sand, silt, and clay and is up to 100 m thick (Figure 2). Maximum clast sizes range from pebble to cobble, with boulder-sized clasts reported locally at the surface, particularly in the Stayton basin. Also

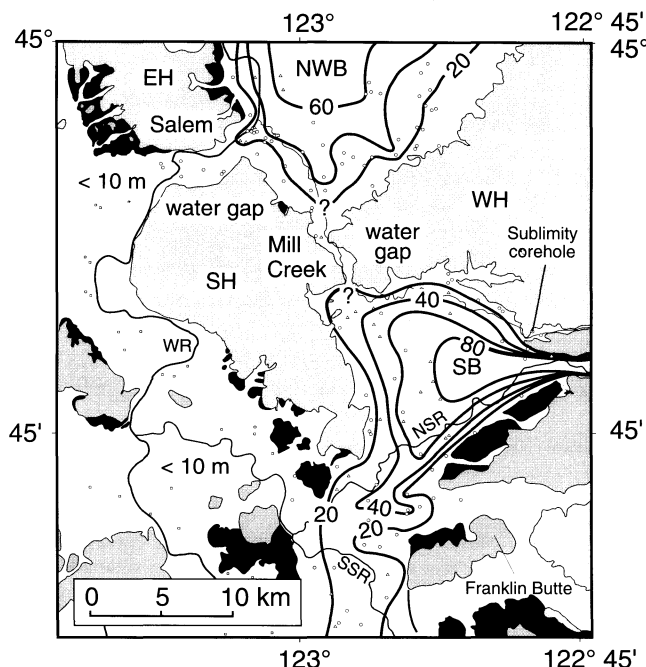


Figure 2. Isopach map of gravels underlying the surface of the Linn fan, in meters. Older terrace gravels, after Yeats and others (1991), are shown in black. Open circles = wells penetrating the base of the gravel deposit, open triangles = wells providing a minimum thickness, open squares = approximately located wells from Yeats and others (1991). WR = Willamette River, NSR = North Santiam River, SSR = South Santiam River.

present are thick sections of fine-grained sediment at small drainages, including Mill Creek, McKinney Creek, and the Pudding River (Figure 3). Interfingering and lateral juxtaposition with gravels suggest these sediments were deposited on the distal reaches and margins of gravel outwash fans. The lower section of the basin fill is dominated by fine-grained sediments consisting of sand, silt, and clay. Detailed drill hole logs commonly report alternating layers of finer and coarser material, and some logs note minor intervals of gravel (up to 2 m thick), wood (up to 7 m thick), and volcanic ash. In the center of the Stayton basin, the maximum thickness of fine-grained sediments is 115 m (Figure 3).

Gravels comprising the upper section of valley fill in the study area form a massive alluvial fan that extends across the Stayton basin and into the northern Willamette basin (Figure 4). This fan is buried beneath a wedge of late Pleistocene catastrophic flood deposits, which is thickest in the northern Willamette basin. Structure contours on the top of the gravel facies show the constructional surface of the youngest outwash deposit, the Linn gravels (Figure 5). The fan surface bifurcates against the Salem Hills and extends into the northern Willamette Valley through a 1-km-wide water gap occupied by Mill Creek, demonstrating that the ancestral North Santiam River transported Linn gravels into the Willamette basin.

We infer that the ancestral North Santiam River is the primary source for the deep gravels in the Salem metropolitan area, because (1) these gravels form a continuous fanlike geometry; (2) no other

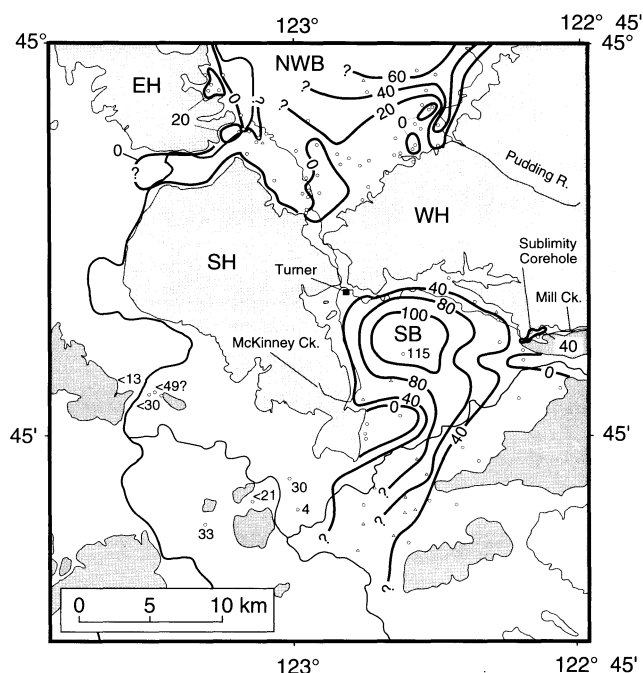


Figure 3. Isopach map of fine-grained sediments in the valley fill. For symbols and abbreviations, see Figures 1 and 2. Numbers in smaller type are thicknesses in meters interpreted from adjacent oil wells. Contour interval is 40 m with supplemental contours at 20 m.

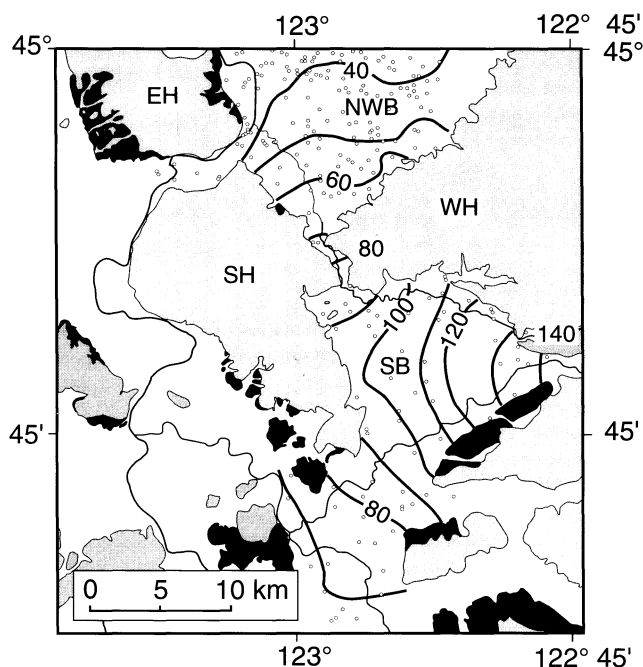


Figure 5. Structure contour map of the top of Linn gravels. Open circles = wells penetrating the upper gravel section of the valley fill. Older terrace gravels, after Yeats and others (1991), are shown in black. Contour interval is 10 m.

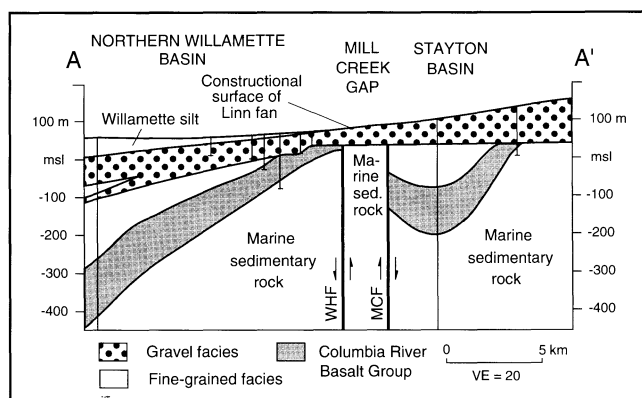


Figure 4. Geologic cross section through the Mill Creek water gap along the crest of the Linn gravel fan, showing fan gravels deposited by the ancestral North Santiam River and well control. Section location shown in Figure 1.

drainages, aside from the Willamette River, are capable of transporting a large volume of gravels into the south end of the northern Willamette basin; and (3) gravels along the course of the Willamette River are thin and discontinuous and do not form a thoroughgoing channel deposit (M. Gannett, written communication, 1993).

Core-hole magnetostratigraphy: In holes near the towns of Corvallis and Sublimity (Figure 1), the Oregon Department of Transportation continuously cored sections of the valley fill with about 90 percent recovery. Alternating-field and thermal demagnetization of specimens from these cores yielded stable remanent magnetic inclinations. The polarity log of the Sublimity core shows a long reverse segment bounded above and below by predominantly normal polarity zones (Figure 6). The Corvallis core is mostly normal except for one zone of alternating polarity at about 40 m mean sea level (MSL), which is considered unreliable, because each

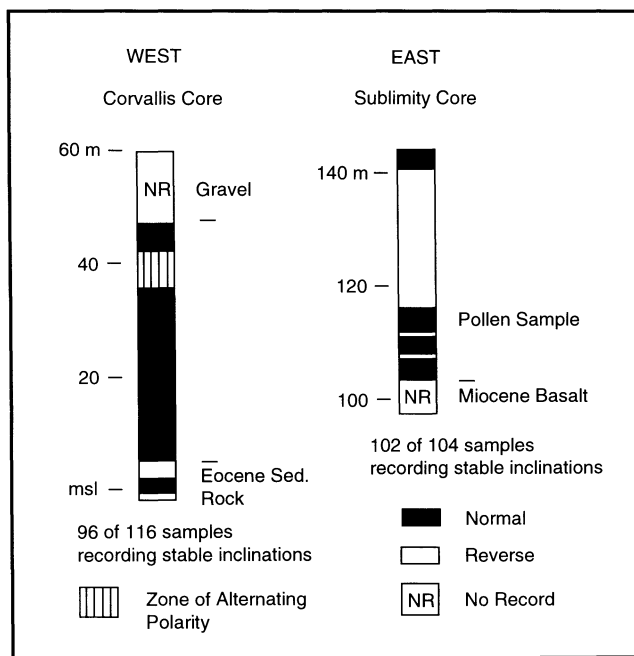


Figure 6. Magnetic polarity of cores drilled by the Oregon Department of Transportation at Corvallis and Sublimity. Core hole locations shown in Figure 1.

reverse interval is a one- or two-sample spike, and the specimens have relatively unstable remanence. The reverse polarity segment at the bottom of the Corvallis core is in the Eocene Spencer Formation (Yeats and others, 1991).

Fossil pollen, sampled from a depth of 31.8 m in the Sublimity core, were analyzed by C. Whitlock at the University of Oregon. The

pollen assemblage suggests a period of open parkland with spruce and pine as the dominant conifers. An herb indicative of alpine conditions is also present, while exotic taxa are absent (C. Whitlock, written communication, 1992).

Because no significant reversals are recognized in the Brunhes geomagnetic-polarity epoch (or chron), the long reverse polarity zone in the Sublimity core indicates that the cored sediments below 140 m MSL are older than 0.78 Ma (Hilgen, 1991; Zijderveld and others, 1991). Correlation of the long reverse zone with the Matuyama chron is preferred, given a glacio-fluvial outwash interpretation for the core sediments (discussed later). However, based on the paleomagnetic data alone, the possibility that the reversely magnetized sediments belong to the Gilbert chron can not be excluded. The pollen assemblage is more consistent with a Matuyama interpretation, because it is suggestive of a climate cooler than today's. Thus, the Sublimity core probably records Pliocene to middle Pleistocene sedimentation.

STRUCTURE

Figure 7 summarizes the late Cenozoic structure of the study area. Identification of these structures is based largely on deformation of the Columbia River Basalt Group. Therefore, inferences about flow emplacement in the northern Willamette Valley are crucial to interpretation of the tectonic history. The basic assumption is that the top of the Columbia River Basalt Group originated as a relatively planar surface, providing a datum from which vertical tectonics can be measured. We believe this assumption is valid, because the great areal extent, long distance from the source, and huge volume of these lavas, particularly the Grand Ronde Basalt, are indicative of fluid flow conditions.

Willamette Valley synclinorium

In the study area, the Columbia River Basalt Group is warped into a north-south-trending structural trough that comprises the core of the Willamette Valley synclinorium (Figures 8b and 9). The east limb of this trough is characterized by gently westward dipping basalt (about 1.7°) in the foothills of the Western Cascades. Similarly, the west limb of the trough is marked by northeast-sloping cuestas comprising the Salem Hills and Eola Hills. Structure contours show that the basalt in these hills tilts 2°–4.5° northeast (Figure 8). Beeson and others (1989) first recognized these cuestas as tectonic features, naming them the Salem-Eola Hills homocline. The northeast dip direction of the homocline suggests that it is more a result of local tilting on the margins of the northern Willamette and Stayton structural basins than regional tilting on the eastern slopes of the Coast Range. The maximum structural relief on the Columbia River Basalt Group between the Salem Hills and the northern Willamette basin is 820 m (Yeats and others, 1991; this study).

Stayton basin

The Stayton basin is an oblate depression with 400 m of structural relief on the top of the Columbia River Basalt Group (Figure 9). The pattern of deformation is that of a northwest-trending fold bounded by high-angle faults orthogonal to the fold axis. Broad downwarping controls subsidence at the southwest and northeast margins of the basin, while a northeast-trending fault pair controls subsidence at the

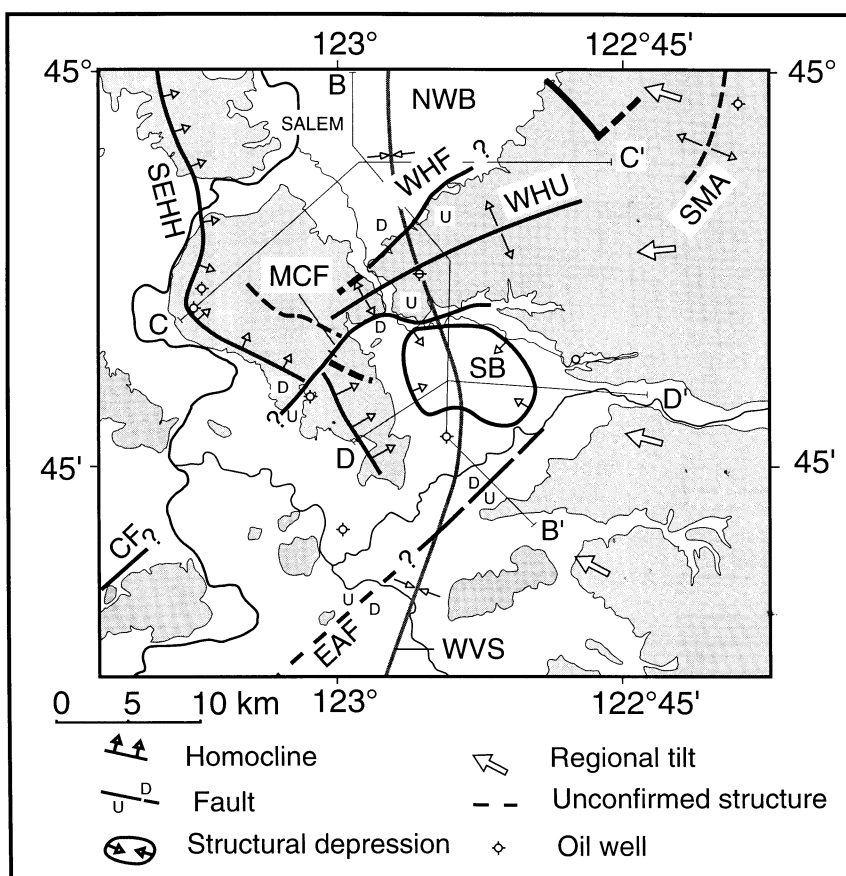


Figure 7. Neotectonic map showing structures that deform the Columbia River Basalt Group. WVS = Willamette Valley synclinorium, SEHH = Salem-Eola Hills homocline, WHF = Waldo Hills fault, MCF = Mill Creek fault, WHU = Waldo Hills uplift. Structures on which no post-Columbia River Basalt Group activity is documented include the Scotts Mills anticline (SMA), the east Albany fault (EAF), and the Corvallis fault (CF).

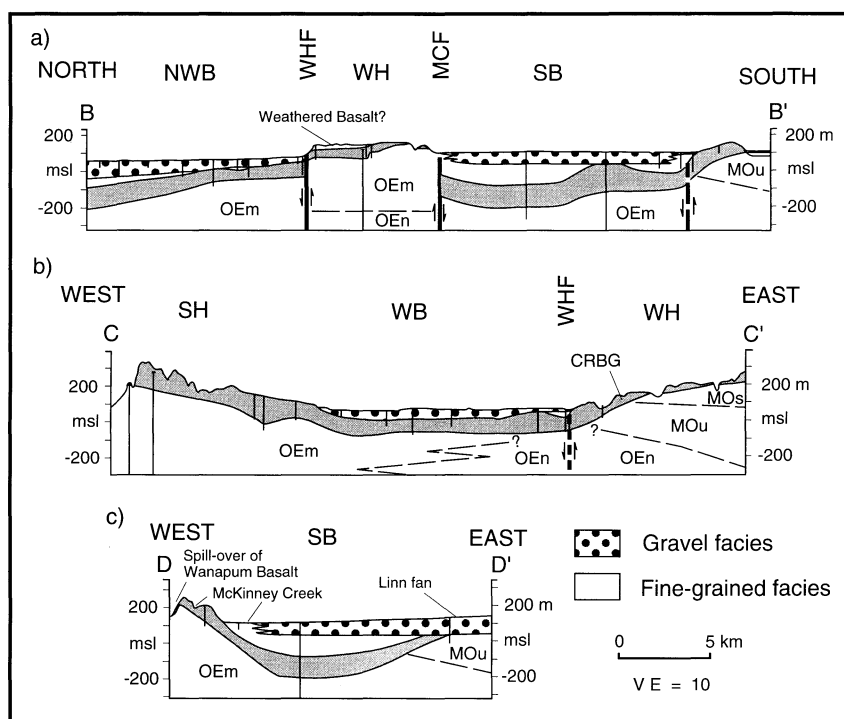
northwest and southeast margins (Figures 8a, 8c, 9). At the northwest margin, vertical displacement on the Mill Creek fault is pronounced. Faulting along the southeast margin is less clear, but water wells constrain a steep drop of at least 80 m in the upper surface of the basalt.

Basalt at the southwest margin of the basin tilts eastward at 4.5°, roughly twice that of basalt in the northern Salem Hills and Eola Hills (Figures 8b, 8c, 9). This contrast in dip demonstrates that the wavelength of folding in the Stayton basin is shorter than that of the synclinorium and the northern Willamette basin, and hence the Stayton basin must have subsided independently.

Folding of the Stayton basin may reflect sag into a pull-apart structure associated with lateral-slip faults bounding the basin. This interpretation is similar to that for the Portland basin, which is bound by dextral strike-slip and dip-slip faults (Beeson and others, 1989; Yelin and Patton, 1991) and is consistent with the current north-south compressive stress of western Oregon (Werner and others, 1991).

Northern Willamette basin

The northern Willamette basin is a northeast-southwest elongate depression that straddles the regional downwarping axis of the Willamette Valley. Up to 550 m of basin fill overlies the Columbia River Basalt Group, which, in the center of the basin, has subsided to 500 m below sea level (Yeats and others, 1991). Local structures controlling the margin of the basin are not well defined (Beeson and others, 1989; Yeats and others, 1991), except in the southwest corner along the Waldo Hills fault. Structure contours show that the top of the basalt drops off rapidly at the base of the Eola Hills; however,



Left:

Figure 8. Geologic cross sections. Heavy long dash indicates inferred fault. Heavy short dash is possible fault extension. Fault dips are unknown. Geology, after Yeats and others (1991), is as follows: Shaded pattern = Columbia River Basalt Group (CRBG); WB = Willamette basin, msl = mean sea level; MOs = marine and nonmarine sedimentary rocks, MOu = strandline sedimentary and volcanic rocks, OEm = marine sedimentary rocks, OEn = volcanic and nonmarine sedimentary rocks. For other abbreviations, see Figures 1 and 2. Section locations are shown in Figure 7.

Below:

Figure 9. Structure contour map of the top of the Columbia River Basalt Group. Open circles = wells penetrating basalt. Open triangles = wells constraining the depth to basalt. Solid lines = faults. Dashed line = inferred fault. Contour interval is 80 m. For symbols and abbreviations, see Figures 1, 7, and 8.

well data are not dense enough to determine whether this boundary is fault controlled (Yeats and others, 1991).

Waldo Hills uplift

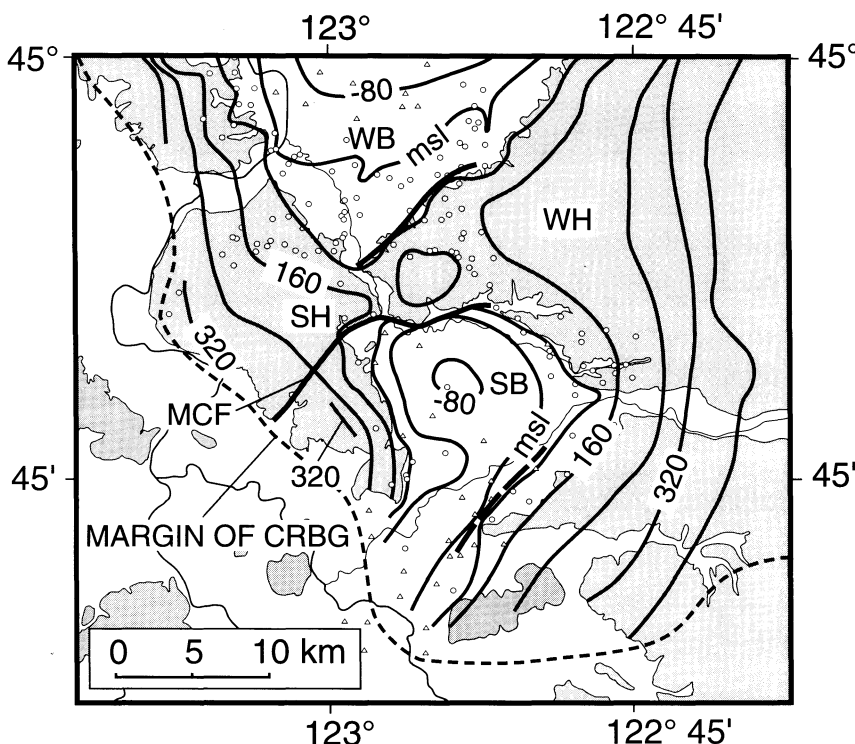
The Waldo Hills uplift deforms the Columbia River Basalt Group into a broad, asymmetrical arch following a northeast-southwest trend (Figure 9). This uplift axis crosses the north-south axis of the Willamette Valley synclinorium and imparts a doubly plunging geometry to the structural trough at the core of the synclinorium. At the intersection of the axes, the contrast in deformational polarity is strongest, and the Waldo Hills form a narrow upfaulted block bounded between the Mill Creek and Waldo Hills faults (Figure 8a).

Mill Creek fault

A 16-km-long fault with pronounced vertical displacement transects the Salem Hills at the town of Turner and follows along the southern range front of the Waldo Hills (Figures 7, 9). Previous workers identified this fault as two separate structures, naming it the Turner fault in the Salem Hills and the Mill Creek fault in the Stayton basin (Yeats and others, 1991). The maximum vertical fault displacement of the upper surface of the Columbia River Basalt Group is estimated to be 150 m but may be as much as 210 m (Figure 8a). Given the large vertical offset and short fault length, the dip of the fault plane is probably steep.

Waldo Hills fault

The northern range front of the Waldo Hills forms a prominent, 40-km-long geomorphic lineament following the northeast-southwest structural trend of western Oregon (Wells and Peck, 1961; Yeats and others, 1991; Nakata and others, 1992). A geologic cross section



constructed from water well logs confirms that the base of the Columbia River Basalt Group is displaced vertically by at least 90 m at the range front (Figure 8a). Moderately well constrained structure contours reflect vertical offset of both the base and top of the basalt along the southern 7 km of the lineament, but it is uncertain whether the fault continues to the northeast. The linear nature of the range front suggests that the fault plane is steeply dipping, and water wells, shown in cross section, indicate that the fault dips more than 60°, if the dip direction is to the northwest.

TECTONIC AND PALEOGEOGRAPHIC EVOLUTION

Early to middle Miocene (pre-Grande Ronde Basalt)

The area that now forms the northern half of the Willamette Valley was rapidly, perhaps catastrophically, inundated by lava flows of the Grande Ronde Basalt (Beeson and others, 1989). With few exceptions, this influx of lava completely buried a low-relief erosion surface. Hence, paleogeography at the time of burial can be reconstructed from isopach maps and relief on the basal contact of the Grande Ronde Basalt.

Highland areas, characterized by primary flood-basalt thicknesses of 40–80 m, included the Waldo Hills and the Western Cascades (Figure 10). Highlands in the Waldo Hills probably resulted from tectonic uplift on trend with the Scotts Mills anticline, a structure identified from low-angle dips (less than 10°) in Oligocene to early Miocene age strata (Miller and Orr, 1986). Considering the spatial coincidence of these narrow highlands with the location of the range-bounding faults, it is likely that the Waldo Hills uplift was active in the early to middle Miocene. This timing is coeval with folding of the Scotts Mills anticline (Miller and Orr, 1986) and supports linkage of the two structures.

Lowland areas, characterized by primary basalt thicknesses of 80–160 m, included the Stayton basin, the southern Willamette basin, and the Salem-Eola Hills, which now form inverted topography. Discontinuous fingers of basalt, 120 m to 180 m thick, appear to mark a system of preexisting channels connecting these lowlands. Dense well control in the Salem Hills demonstrates 100 m of relief on the basal contact of the basalt west of the ancestral Waldo Hills (see Figure 10). This channel probably extended eastward across the Stayton basin to connect with thick basalt, inferred from structure contours, following the modern channel of

the North Santiam River. Four wells, on a north-south transect across the river, define a 4-km-wide channel in sedimentary rock, with at least 30 m of relief on the basal contact of the basalt. An outlier of Grande Ronde Basalt at least 150 m thick (Yeats and others, 1991) lies farther up the river drainage and is a likely extension of this channel. Similarly, a 120-m-thick outlier of Grande Ronde Basalt at Franklin Butte probably marks a smaller tributary channel.

The margin location and the inferred bend in the main lowland channel suggest that Grande Ronde flows abutted against highlands in the southern Willamette Valley that were contiguous with the Salem and Eola Hills. These highlands would have prevented flows from proceeding farther southward and forced backfilling of drainages exiting the Cascades. If this interpretation is correct, these west-flowing drainages were the headwaters of the ancestral Willamette River, and the southern Willamette Valley had not yet formed.

Middle Miocene to Pliocene (post-Grande Ronde Basalt)

Emplacement of the Grande Ronde Basalt forced drainage to the west side of the ancestral Willamette Valley and established a west-flowing channel across the incipient Coast Range; later flows, belonging to the Wanapum Basalt, spilled into paleochannels incised at the margins of the Grande Ronde Basalt and reached the coast (Beeson and others, 1985, 1989; see Figure 8c). Subsequent downwarping of the Willamette Valley synclinalorium deflected the ancestral Willamette River towards the central axis of the valley.

Middle Miocene uplift of the Waldo Hills, however, may have blocked a route through the subsiding Stayton basin and deflected the river west of the Salem Hills. The Salem water gap is incised into the Salem-Eola Hills homocline, while the alternate route, the

Mill Creek water gap, is incised into the Waldo Hills uplift. Uplift of Columbia River Basalt Group in the Salem and Eola Hills is twice that in the Waldo Hills, 320 m MSL and 160 m MSL, respectively. This suggests that the ancestral Willamette River continuously occupied the Salem gap in order to maintain an incision rate that kept pace with the fastest long-term uplift rate in the study area.

Fault-controlled uplift of the Waldo Hills after emplacement of the Columbia River Basalt Group is indicated by roughly equal amounts of (1) relief (about 90 m) on the upper surface of the basalt and (2) vertical displacement on the lower contact of the basalt across the Waldo Hills fault. This episode of active faulting ended before deposition of the North Santiam gravel fan, the base of which exhibits little or no vertical displacement (see Figure 4). Extensive erosion and degradation of the fault escarpment that forms the northern range front of the Waldo Hills provides a similar constraint on the age of faulting. The sinuosity of fault-controlled range fronts (i.e., measured length of the piedmont-range junction) serves as an index of tectonic activity (Bull and McFadden, 1977). The sinuosity ratio of the northern range front of the Waldo Hills is 1.7, a value characteristic of low fault activity.

In the late Miocene, the Salem-Eola Hills homocline, in concert with the Waldo Hills uplift, formed a continuous belt of uplift extending across the central Willamette Valley. This uplift belt acted as a tectonic dam, obstructing the ancestral Willamette River and causing a thick section of basin-fill sediments to accumulate in

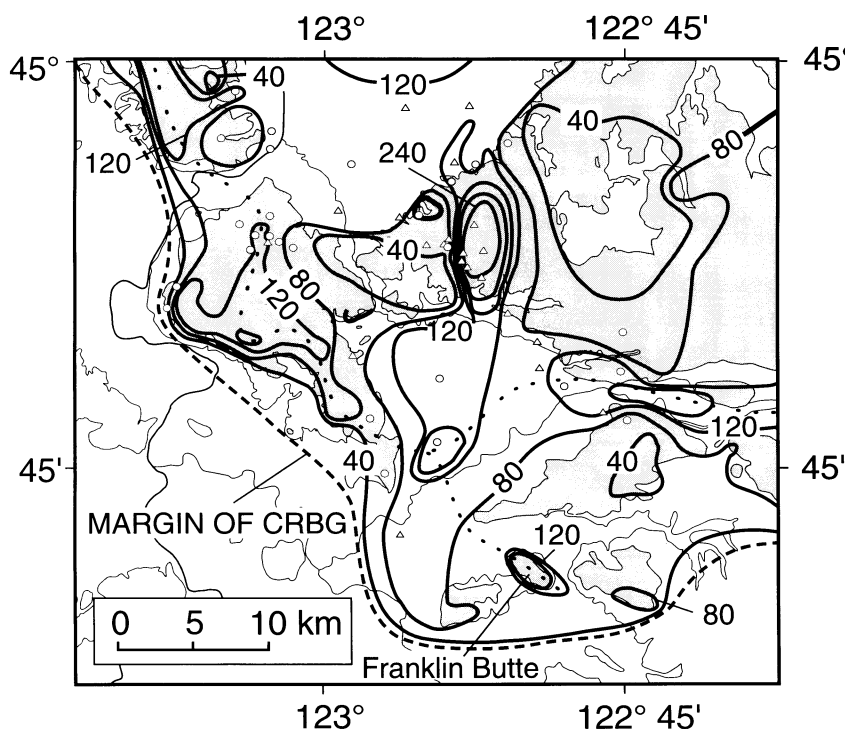


Figure 10. Isopach map showing the restored thickness of the Columbia River Basalt Group. Erosion in drainages less than 4 km wide is restored. Shaded area shows surface exposure of the basalt. Open circles = wells penetrating the base of basalt or older bedrock. Open triangles = wells that do not reach the base of basalt. Dotted lines = inferred drainage channels buried by Grande Ronde Basalt. North-trending area of anomalously thick basalt in Waldo Hills includes subcrop of older basalt. Contour interval is 40 m.

the southern valley. Coeval subsidence of the Stayton and northern Willamette structural basins led to deposition of thick sections of sediments in these basins as well.

Pliocene-Pleistocene

Tectonic subsidence of the northern Willamette basin was synchronous with deposition of fan gravels deposited by the ancestral North Santiam River, while active subsidence of the Stayton basin ceased. In the Stayton basin, the lower boundary of the gravel fan is undeformed, defining an essentially flat-lying interface (Figure 4). North of the Waldo Hills uplift, however, the lower boundary of the gravels inclines into the northern Willamette basin at about 0.1 percent grade. A corresponding increase in gravel thickness from 20 m to 60 m records differential subsidence across the margin of the basin (Figure 2). North of latitude 45°N., these gravels extend into the center of the northern Willamette basin as a series of tectonically inclined layers, reaching depths below -100 m MSL (M. Gannett, written communication, 1993).

The rate of subsidence was probably greater along the southwest margin of the northern Willamette basin, where the gravels thicken most abruptly (Figure 2). Gravels in the Salem water gap fill a bedrock channel that slopes at about 0.8 percent grade, 25 times steeper than the modern channel of the Willamette River. Inclination of this channel records either tectonic tilting and uplift of the Salem-Eola Hills homocline, dip-slip faulting and uplift of the northern Salem and Eola Hills, or burial of a topographic step and falls between the two basins—or a combination of the latter two.

The Sublimity core sediments were deposited in a small drainage immediately adjacent to the head of the North Santiam gravel fan (see Figure 2). Deposition in the drainage was presumably controlled by aggradation of the upper half of the fan, which is laterally equivalent to the core section. If this interpretation is correct, the majority of the gravels in the subsurface are older than 0.78 Ma (middle Pleistocene), and the valley fill aggraded to its present elevation (about 140 m MSL) before the polarity change with which the Brunhes epoch begins. Tectonic changes in the elevation of the core site, since deposition of the cored sediments, are probably small, because (1) the base of the gravel fan is undeformed in the Stayton basin and (2) the core site lies at the boundary between uplift in the Western Cascades and subsidence in the Stayton basin.

Holocene

A broad convexity in the modern profile of the Willamette River suggests that the Salem-Eola Hills homocline is uplifting relative to the northern Willamette basin (Figure 11b). This convexity, which is centered around the city of Salem, closely resembles deformed river profiles in case studies of active uplift zones and flume experiments (Gregory and Schumm, 1987). The alternative hypothesis is differential channel incision due to varying channel lithology.

There are two principal areas where the Willamette River is forced to flow across erosionally resistant bedrock (Figure 11b). At Oregon City, a 10.5-km-long stretch of the river channel is incised into basalt, and the profile forms a single knickpoint, at the downstream edge of the exposure, that is migrating upstream. At the Salem water gap, incision into marine sedimentary rock and basalt along an 11-km-long stretch of channel is inferred from drill hole logs. Another possible lithologic influence is control of

the profile by cemented gravels of the Linn fan. However, down-gradient steepening of the profile in the northern Willamette basin is more in accordance with tectonic subsidence than with the undeformed constructional surface of an alluvial fan.

The spatial dimensions of the convexity correlate well with the uplift zone of the Salem-Eola Hills homocline and poorly with the bedrock incision into the Salem water gap (Figure 11). The uplift zone, as indicated by elevation of Columbia River Basalt Group above the valley floor, is 15 km wide. The Willamette River crosses this zone between river km 119 and 166, matching the location and width of the convexity (about 50 km). In contrast, the maximum length of the bedrock-lined channel in the Salem water gap is roughly 11 km, only one-fourth the width of the convexity. The highest river gradient associated with the convexity is aligned with the downriver margin of the uplift zone, while drill hole logs show that the margin of the bedrock incision lies 18 km farther upriver (Figure 11).

The evidence considered here is most consistent with a tectonic origin for the broad convexity. However, further study of the Willamette River, its tributaries, and the geomorphic surfaces in the Willamette Valley is needed to evaluate the possibility of active tectonic deformation.

CONCLUSION

The regional structure of the Salem metropolitan area is a broad, north-south trending structural trough that comprises the core of the Willamette Valley synclinorium. Short northeast- and northwest-trending faults subdivide this trough into smaller structural basins, which include the northern Willamette basin and the Stayton basin. These two basins are separated by the Waldo Hills uplift, a fault-bounded block that transects the regional downwarping axis of the Willamette Valley. Miocene uplift of the Waldo Hills is indicated by thinning of the Columbia River Basalt Group and deflection of the Willamette River west of the structural axis of the valley. Uplift of

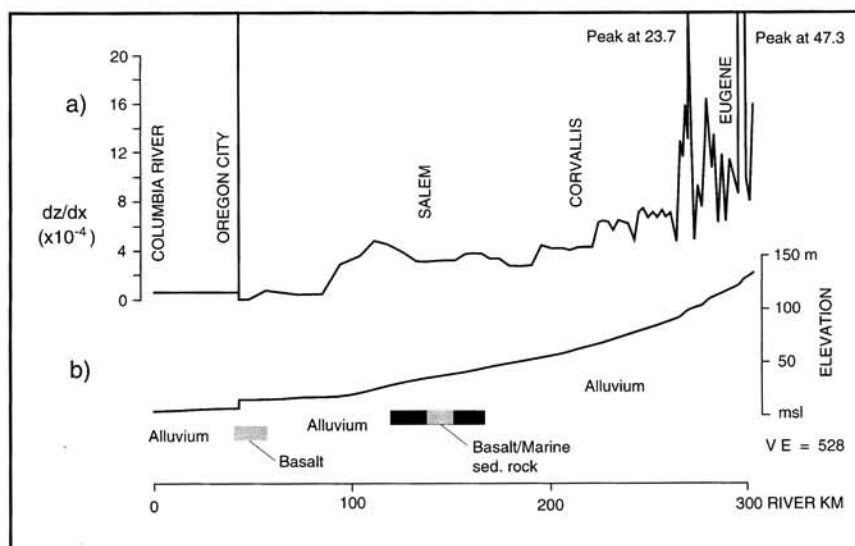


Figure 11. Gradient plot of the Willamette River (a) and longitudinal profile of the Willamette River from its confluence with the Columbia River to the juncture between the Coast Fork and Middle Fork (b). In (a), the broad, low-amplitude increase in gradient north of Salem is associated with a broad convexity in the profile. Spikes near Eugene may be associated with bedrock incisions and/or coarse sediment influxes from the McKenzie River. In (b), the black bar shows uplift zone of the Salem-Eola Hills homocline as defined by elevation of Columbia River Basalt Group above the valley floor. Shaded bar and text indicate geology of the river channel. Both figures are based on Balster and Parsons (1968) between river kilometers 0 and 95 and were constructed from U.S. Geological Survey 7½' topographic mapping between river kilometers 96 and 301.

the Waldo Hills, in concert with uplift and tilting of the Salem-Eola Hills homocline, formed a tectonic dam that caused a thick section of fine-grained alluvial sediments to accumulate in the southern Willamette Valley.

With the onset of Pliocene-Pleistocene glaciation, a massive alluvial fan associated with the ancestral North Santiam River was deposited in the upper section of the valley fill. These fan gravels traversed the Waldo Hills uplift through a 1-km-wide channel connecting the Stayton and northern Willamette basins. Increasing gravel thickness in the northern Willamette basin indicates that the deposition was synchronous with tectonic subsidence of the basin. Tentative correlation with paleomagnetic and pollen core data suggests that the subsurface gravels are Pliocene to middle Pleistocene.

Holocene uplift of the Salem-Eola Hills homocline relative to the northern Willamette basin is suggested by a broad convexity in the modern longitudinal profile of the Willamette River. Although the long-term rates of vertical deformation are very low, on the order of 10^{-2} mm/year, the magnitude 5.6 oblique-strike-slip earthquake of 1993 near Scotts Mills demonstrated that deformation is continuing.

ACKNOWLEDGMENTS

We thank Marshall Gannett, Scott Burns, Rod Caldwell, Bernard Kleutsch, Cathy Whitlock, Haruo Yamazaki, Alan Niem, and Gordon Grant for providing thoughtful input and aid in acquiring data during this project, and especially Marshall Gannett and Scott Burns for reviewing an early version of this manuscript. The project was supported by the National Earthquake Hazards Reduction Program (Agreement No. 14-08-0001-G2131), and computer facilities were provided by the Geological Survey of Japan.

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THESIS ABSTRACTS

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

A study and comparison of portions of the Huntington-Olds Ferry and Wallowa-Seven Devils volcanic arc terranes, by Patti M. Goebel (M.S., University of Oregon, 1990), 130 p.

The Clover Creek greenstone of the Wallowa-Seven Devils arc is found to be Permian rather than Triassic as previously believed. The volcanic sequence of the Clover Creek rocks is bimodal, dominated by keratophyre (dacite) flows and tuffs with minor spilite (basalt) flows. This assemblage is representative of immature island-arc or forearc volcanism. The same volcanic assemblage is also found in the other Permian volcanic rocks from both the Wallowa-Seven Devils and Huntington-Olds Ferry terranes. The Clover Creek rocks have undergone low-temperature metamorphism and diagenesis. The main metamorphic assemblages are the zeolite and pumpellyite-prehnite facies, which are representative of burial metamorphism beneath a growing volcanic pile. The Triassic Huntington greenstones of the Huntington-Olds Ferry terrane are characterized by a complete range of volcanic rocks, with andesite being the most abundant. This assemblage is also found in the other Triassic arc rocks of the Wallowa-Seven Devils terrane. The metamorphic/diagenetic assemblage of the Huntington greenstones differs from that of the Clover Creek rocks. Assemblages in the Huntington rocks probably reflect shallow burial or hydrothermal metamorphism as opposed to the somewhat deeper burial metamorphism of the Clover Creek rocks.

Geology and geochemistry of epithermal gold mineralization in the Lake Owyhee volcanic field-western Snake River Plain region of eastern Oregon and western Idaho, by Brian S. Zimmerman (Ph.D., Washington State University, 1991), 262 p.

The Lake Owyhee volcanic field-Western Snake River Plain region of Oregon and Idaho contains over 30 epithermal gold prospects. Mineralization occurs in a number of diverse geologic settings and hydrothermal environments.

Mineralization on Indian Head Mountain, Idaho, occurs in a lateral fluid flow regime. Fluids moving laterally within a confined aquifer discharged into overlying fault breccias during periods of high fluid flow. Quartz-pyrite veins and breccias are present within the dacite flow which served as the aquifer. Anomalous Au concentration, accompanied by elevated As, Sb, Hg, and Mo concentrations, are found in samples containing abundant pyrite. The overlying fault breccias host quartz-pyrite veins as well as quartz-chlorite/smectite and calcite veins that contain electrum. Mineralization occurred in response to mixing of hydrothermal fluids with cooler groundwaters.

Hydrothermal activity at Red Butte, Oregon, was concurrent with deposition of coarse grained fluvial sediments. This association is typical of epithermal gold prospects in the region. Examples of many of the features of a hot spring Au deposit are exposed on Red Butte, including: siliceous sinter, a blanket of argillic alteration produced by steam-heated waters, and a hydrothermal eruption crater filled with bedded breccia deposits. Electrum is found in quartz-adularia veins below the argillic alteration. Mineralization occurred both in response to fluid boiling and mixing of the boiling fluid with steam-heated waters.

Geochemical comparison of five epithermal gold prospects from the region reveals that, in general, there is more variation within a given prospect than there is among prospects. The Katey and Bannock prospects, which are spatially related to high-silica rhyolite

domes, are enriched in Ag, Se, Mo when compared to the other prospects. Mineralization areas containing large amounts of pyrite are enriched in As, Ag, Sb, and Mo.

Potential petroleum reservoir rocks of north-central Oregon, by Alfred J. Riddle (M.S., Loma Linda University, 1990), 240 p.

Petroleum explorationists have commonly assumed, based on the presence of volcanic and/or volcanoclastic rock, that regions such as north-central Oregon do not hold potential as petroleum basins. The typical argument has been that volcanic flows have no effective porosity or permeability and that poorly sorted volcanoclastic sediments contain a high percentage of mineralogically unstable grains that are too easily and rapidly altered into clays and zeolites for any significant or effective porosity to be retained.

The objective of this study was to determine whether potential petroleum reservoir rocks do exist in north-central Oregon. Through field and laboratory study and by comparing this region with petroleum-producing basins with volcanic and volcanoclastic reservoirs, I have determined that the potential volcanic and volcanoclastic reservoirs of this area cannot be entirely "judged" by the "rules" of average siliciclastic reservoirs. Secondary dissolution and fracture porosity are extremely important in these reservoirs and are the natural consequence of hydration reactions, the formation of organic acids during thermal maturation of associated organic-rich source rocks, high geothermal gradients that increase the rate of dissolution of some grains, the flushing of dissolution products out of the reservoirs during diagenesis, and the development of fracture porosity in a tectonically active area. As a result of this study, I have concluded that north-central Oregon does in fact have good potential petroleum reservoir rocks.

Ocean shore protection policy and practices in Oregon: An evaluation of implementation success, by James W. Good (Ph.D., Oregon State University, 1992), 276 p.

Oregon's beaches were designated public recreation areas by the 1967 Beach Law. These beaches and adjacent shorelands experience erosion and other hazards due to winter storm waves, weathering, and geologic instability. Sea cliff recession threatens older development, and inadequate construction setbacks create hazards for new buildings. The typical hazard response is to install a hard shore protection structure (SPS).

An evaluation of shore protection and land use policy implementation, factoring in recent advances in our understanding of coastal processes and engineering, suggests that policies designed to mitigate hazards and protect the beach are not working well.

Five state laws that make up the "shore protection management regime" were examined using an ocean-front, tax-lot-based geographic information system (GIS) for the 16-mile long Siletz littoral cell on the central coast. Policy objectives were determined, measures of achievement and related data needs were identified, and the GIS designed accordingly. Seven principal shore protection policy objectives and 25 measures of achievement were identified. GIS queries related to these measures revealed that 49 percent of the Siletz cell beach front has been hardened with SPSs—69 percent of it since the 1967 Beach Law. Because of jurisdictional gaps, 31 percent of the post-1967 SPSs were not regulated. For those that were regulated and approved, no clear need could be determined in 35 percent of the cases. Also, 28 percent of the SPSs were installed on vacant lots, often because local officials required a SPS before owners could obtain a building permit. This and other findings, such as inadequate construction setbacks, suggest that land use decisions, more than erosion hazards, are driving the demand for beach front SPSs.

In the SPS permit process, alternatives to hard SPSs are not thoroughly evaluated. SPSs are typically over-designed, and many encroach on the public beach, affecting access. Cumulative SPS impacts are significant, especially the blocking of 39 percent of the sand supply from eroding sea cliffs. Given expected future erosion

and relative sea level rise along the central Oregon coast, some beaches may gradually disappear.

Based on this analysis, Oregon's ocean shore protection management regime needs an overhaul. Addressing these policy issues now will help preserve Oregon's beaches for future generations.

Geology and geochemistry of a portion of the eastern Clarno Formation, Grant County, Oregon, by Sandra P. Lilligren (M.S., Washington State University, 1992), 155 p.

Two stratigraphic sequences are distinguished within the mid-Tertiary calc-alkaline Clarno Formation in northeast Oregon and have been identified by combining field mapping, geochemical analyses, and petrography.

The lower sequence is dominated by andesite and dacite flows but also contains basalt with relatively high FeO* and TiO₂ concentrations. It is more alkaline than the upper sequence, contains Nb concentrations ranging from 18 to 62 ppm, and is dated at 39.9 to 36.7 Ma. The upper sequence, with ages from 37.6 to 33.6 Ma, is andesite and hornblende-phyric dacite and is overlain by olivine-phyric basalt with high Sr concentrations. Nb concentrations in the upper sequence are <23 ppm. Both sequences are intercalated with voluminous volcanoclastic debris flows. All flows are chemically and physically variable and cover very limited areas. Their relatively primitive isotopic signature (Sr_i = 0.70343 to 0.70370, and Nd_i = 0.512830 to 0.512893) implies an origin from a source or sources not long removed from the convecting asthenosphere.

No simple continuum exists between either of the two sequences or between them and the andesite-dominated western Clarno, where most earlier studies of the Clarno have concentrated. The western Clarno is less alkalic than the eastern, and the three sequences vary in Nb and total alkali contents over a similar SiO₂ range.

It is argued that simple fractionation cannot be the controlling factor in causing chemical variation between and within each of these sequences. Rather, mixing of silicic (crustal) and basaltic (mantle) components is suggested by the petrographic and chemical evidence. Variety in the mantle component could originate from three separate sources or could result from partial melts of variable degree and depth from one source. The Clarno is similar to calc-alkaline assemblages associated with subduction environments along continental margins but is probably a product of regional extension, which permitted the partial melting of both enriched sub-lithospheric mantle and crust created by earlier subduction events during the Mesozoic.

Geology and petrology of a 26-Ma trachybasalt to peralkaline rhyolite suite exposed at Hart Mountain, southern Oregon, by Allyson C. Mathis (M.S., Oregon State University, 1993), 141 p.

Rocks older than the Steens Basalt in southeastern Oregon are mainly exposed in prominent fault scarps such as Steens Mountain, Hart Mountain, and Abert Rim. At Hart Mountain, the section consists of a suite of trachybasalt to trachyte to peralkaline rhyolite lava flows and tuffs. The Hart Mountain volcanic complex contains the only known pantellerites and the oldest peralkaline rhyolites (26.3 Ma) in the Basin and Range province.

⁴⁰Ar/³⁹Ar age determinations from feldspar separates from a basaltic trachyandesite near the base (26.48 ± 0.13 Ma; one sigma error) and a peralkaline rhyolite near the top (26.33 ± 0.04 Ma) of the exposed suite are analytically indistinguishable. The ages and the paucity of sedimentary rocks within the conformable section indicate that the volcanic rocks were erupted during a short time interval and that they probably represent a single magmatic system. The Hart Mountain trachyandesite suite, with a thickness of as much as 450 m, makes up the lower portion of the section and consists predominantly of basaltic trachyandesite to trachyte lava flows and tuffs. The upper portion of the sequence, the Warner Peak rhyolite, is at least 150 m thick; it includes most of the exposed near-vent rocks of the Hart Mountain volcanic complex east of the field area and is mostly

pantellerites and comendites with a few interlayered trachytes.

Major and trace element models demonstrate that crystal fractionation of plagioclase > olivine ≈ clinopyroxene > Fe Ti oxides > apatite from a range of alkali basaltic to trachybasaltic parents can account for the Hart Mountain trachyandesite suite. Textural evidence indicates that some mixing also occurred in the trachyandesitic composition range. Approximately 90 percent crystal fractionation is required to produce trachyte from trachybasalt. Approximately 40-50 percent crystal fractionation of trachytic parents is needed to generate the range of peralkaline rhyolites in the Warner Peak rhyolite. Modeling of the petrogenesis of the Warner Peak rhyolite, however, is qualitative because of compositional changes these peralkaline rocks have undergone with crystallization and/or devitrification.

The Hart Mountain volcanic complex is similar to strongly peralkaline volcanic systems, such as Pantelleria, rather than weakly peralkaline centers (e.g., McDermitt caldera, Kane Spring Wash caldera, etc.) exposed elsewhere in the Basin and Range. As in strongly peralkaline centers, the Hart Mountain volcanic complex contains pantellerites and comendites, does not include subalkaline rhyolites or high-silica rhyolites, and consists predominantly of silicic rocks (~ 85 volume percent). Unlike strongly peralkaline centers, the Hart Mountain volcanic complex does not have a silica gap between the mafic and silicic end members. Also, rhyolites of the Hart Mountain volcanic complex do not have the extreme enrichment of incompatible elements (Rb, Zr, REE) that are characteristic of pantellerites found elsewhere.

The well-documented association of peralkaline rhyolites with extensional environments suggests that south-central Oregon was at least an area of local extension in the late Oligocene. Volcanism elsewhere in the Great Basin at that time consisted of calc-alkaline-alkaline intermediate to silicic magmatism.

Geochemistry, alluvial facies distribution, hydrogeology, and ground-water quality of the Dallas-Monmouth area, Oregon, by Rodney R. Caldwell (M.S., Portland State University, 1993), 198 p.

The Dallas-Monmouth area, located in the west-central Willamette Valley, Oregon, consists of Tertiary marine and volcanic bedrock units that are locally overlain by alluvium. The occurrence of ground water with high salinities has forced many rural residents to use public water supplies. Lithologic descriptions from driller's logs, geochemical (INAA), and X-ray diffraction analyses were used to determine alluvial facies distribution, geochemical and clay mineral distinctions among the units, and possible sediment sources. Driller's log, chemical and isotopic analysis, and specific conductance information from wells and springs were used to study the hydrogeologic characteristics of the aquifers and determine the distribution, characteristics, controlling factors, and origin of the problem ground waters.

Three lithologic units are recognized within the alluvium on the basis of grain-size: (1) a lower fine-grained unit; (2) a coarse-grained unit; and (3) an upper fine-grained unit. As indicated by geochemical data, probable sediment sources include: (1) Cascade Range for the recent river alluvium; (2) Columbia Basin plutonic or metamorphic rocks for the upper fine-grained older alluvium; and (3) Siletz River Volcanics from the west for the coarse-grained sediment of the older alluvium.

The Spencer Formation (unit Ts) is geochemically distinct from the Yamhill Formation (unit Ty) and the undifferentiated Eocene-Oligocene sedimentary rock (unit Toe) with higher Th, Rb, K, and La and lower Fe, Sc, and Co concentrations. The clay mineralogy of unit Ty is predominantly smectite (86 percent), while unit Ts contains a more varied clay suite (kaolinite, 39 percent; smectite, 53 percent; and illite 8 percent). Units Ty and Toe are geochemically similar but are separated stratigraphically by unit Ts. The Siletz River Volcanics

are distinct from the marine sedimentary units with higher Fe, Na, Co, Cr, and Sc concentrations. Units Ty and Toe are geochemically similar to volcanic-arc-derived sediments, while unit Ts is similar to more chemically evolved continental-crust material.

Wells that encounter ground water with high salinities (TDS>300 mg/l) (1) obtain water from the marine sedimentary bedrock units or the older alluvium; (2) are completed within zones of relatively low permeability (specific capacities ≤ 5 gpm/ft); and (3) are located in relatively low-lying topographic settings. The poor-quality waters occurring under these conditions may be due to the occurrence of mineralized, regional flow system waters. Aquifers of low permeability are less likely to be flushed with recent meteoric water, whereas upland areas and areas with little low-permeability overburden are likely zones of active recharge and flushing with fresh, meteoric water.

The most saline waters sampled have average isotopic values ($\delta D = -6.7\text{‰}$ and $\delta O = -1.7\text{‰}$) very near to SMOW, while the other waters sampled have isotopic signatures indicative of a local meteoric origin. The Br/Cl ratios of most (10 of 14) of the waters sampled are within 20 percent of sea water. A marine connate origin is proposed for these waters with varying amounts of dilution with meteoric waters and water-rock interaction. The problem waters can be classified into three chemically distinct groups: (1) $CaCl_2$ waters, with Ca as the dominant cation; (2) NaCl waters with Na as the dominant cation; and (3) Na-Ca-Cl waters with nearly equal Na and Ca concentrations. NaCl and $CaCl_2$ waters may have similar marine connate origins but have undergone different evolutionary histories. Na-Ca-Cl waters may represent a mixing of the NaCl and $CaCl_2$ waters.

Late Quaternary crustal deformation on the central Oregon coast as deduced from uplifted wave-cut platforms, by Robert Ticknor (M.S., Western Washington University, 1993), 70 p.

Uplifted wave-cut platforms are used as datum surfaces from which to describe late Quaternary deformation along a 65-km portion of the Oregon coast, between the latitudes of 44.23° and 44.75° N. Within this area, the remnants of six uplifted marine terraces are preserved. Ascending in elevation, they are the Newport, Wakonda, Yachats, Crestview, Fern Ridge, and Alder Grove terraces. Altitudinal surveys, terrace back-edge morphology, cover-bed stratigraphy and soil development were employed as criteria for correlation of platforms. No numerical ages are available for the platforms; however, I estimate the ages of the lowest three by correlation, using soils and amino-acid ratios for fossil shells, to platforms of known age further south on the Oregon coast. The Newport, Wakonda, and Yachats platforms appear to have formed during the 80-, 105-, and 125-ka sea-level high stands. These three lowermost platforms are used to define neotectonic deformation and along-coast trends of uplift rates. In general, platform elevations decrease to the south. The Newport platform (80 ka) is exposed only north of Yaquina Bay, while the Yachats platform (125 ka) is near sea level for the 12-km coastal segment south of Yachats. Late Quaternary faults offset the platforms in two areas. The Yaquina Bay fault trends approximately east-west through Yaquina Bay and has progressively offset the three lowest platforms, down to the south, yielding a vertical slip rate of 0.6 ± 0.06 m/ka. In the vicinity of Alsea Bay, it coincides geographically with the only coseismically buried Holocene marshes on the central Oregon coast, suggesting that the repeated coseismic subsidence events at this site were localized to the downwarp across Alsea Bay and are not necessarily regional in distribution. The uplift rate for the 125-ka terrace decreases to the south, ranging from 0.88 m/ka north of Yaquina Bay to 0.02 m/ka south of Yachats. The latitudinal trend of geodetically derived uplift rates for the past 70 years, in this same coastal reach, is opposite to the trend of uplift rates derived from wave-cut platform elevations. The two trends are coincident at Yaquina Bay, where the Yaquina Bay fault offsets the marine terraces. Given this structural and deformational discontinuity, it is possible that the Yaquina Bay fault coincides geographically

with a segment boundary along the Cascadia margin.

Holocene channel changes of Camp Creek; an arroyo in eastern Oregon, by Karin E. Welcher (M.A., University of Oregon, 1993), 145 p.

In the stratigraphic record of Camp Creek are episodes of fluvial scour and fill thousands of years old.

Radiocarbon dates and the Mazama tephra, which serves as a stratigraphic time line, temporally bracket episodes of vertical aggradation and incision. Before 9,000 years B.P., the valley floor was scoured to the Tertiary bedrock. Aggradation dominated since that time. Large cut-and-fill structures indicate that two periods of erosion occurred prior to incision of the modern arroyo. The first occurred before 6,800 yr B.P., and the second occurred approximately 3,000 years ago. The modern arroyo channel flows at or near the Tertiary bedrock is entrenched as much as 9 m in the valley-fill alluvium and is thought to have originated during the late 19th century.

Geology and mineral resources of the Richter Mountain 7.5-minute quadrangle, Douglas and Jackson Counties, Oregon, by Robert B. Murray (M.S., University of Oregon, 1994), 239 p.

The Richter Mountain 7.5-minute quadrangle, in Douglas and Jackson Counties, southwestern Oregon, is approximately bisected by the contact between pre-Tertiary metamorphic and intrusive rocks of the Klamath Mountains geologic province and Tertiary volcanic rocks of the Western Cascades province.

The metamorphic grade of the serpentinites, amphibolites, and metasedimentary rocks that crop out in the western half of the quadrangle grades from epidote amphibolite facies at the northern edge of the quadrangle to amphibolite facies at the southern edge, near Richter Mountain. Metamorphic fabrics are well developed and indicate that at least two prograde events took place, which have been overprinted by a retrograde event. Isograds and fabrics crosscut all lithologic boundaries and are correlative with amphibolites and schists of the May Creek terrane to the south.

All of the metamorphic lithologies are intruded by the 141-Ma White Rock pluton. Preliminary mapping shows that it is crudely zoned inward from biotite trondhjemite to hornblende tonalite, with minor garnet-muscovite-biotite-bearing late-stage granodiorite, granite, and alkali feldspar granite phases.

Tertiary volcanic rocks crop out over all of the eastern half of the quadrangle. The 34.9-Ma Tuff of Bond Creek is a rhyolitic biotite-plagioclase-quartz phryic welded tuff that divides tuffaceous sediments, with minor interbedded tuffs and mafic to silicic flows, into upper and lower units correlative with the Colestin Formation and Little Butte Volcanics, respectively. In the southern half of the quadrangle the Tuff of Mosser Mountain, a plagioclase-phryic dacitic welded tuff directly overlies the Tuff of Bond Creek.

Origin of compositional variability of the lavas at Collier Cone, High Cascades, Oregon, by James Daniel Schick (M.S., University of Oregon, 1994), 142 p.

Collier Cone is a Holocene cinder cone located in the High Cascades of Oregon. Over a relatively short period of time, it erupted five distinct units. Included in these units are mafic and silicic xenoliths. These units range in composition from basaltic andesite (55 weight percent SiO_2) to dacite (65 weight percent SiO_2) and have phenocryst contents of <10 to 20 volume percent. The observed variations can be explained as the result of mixing of a basaltic andesite, dacite, and an olivine-plagioclase mafic cumulate. The dacite is best modeled as a combination of silicic xenoliths and a mafic component possibly formed by liquid fractionation. The source of the lavas appears to have been a basaltic andesite magma chamber that was capped by dacite and lined by mafic cumulates in the lower reaches. The results of this study demonstrate the complexity of the processes involved in creating monogenetic volcanoes in subduction zone environments. □

DOGAMI PUBLICATIONS

Released September 30, 1994:

Geologic Map of the Remote Quadrangle, Coos County, Oregon, by Gerald L. Black. Released as map GMS-84 in the DOGAMI Geological Map Series. Price \$6.

The Remote quadrangle includes, along its southern edge, the stretch of the Middle Fork Coquille River between Remote and Bridge and extends north as far as Elk Creek, a tributary to the East Fork Coquille River. The quadrangle is at the southwest corner of a block of eight quadrangles for which geologic maps have been already produced or are in progress. Such maps provide basic geologic information about earth resources and geologic hazards that can be used by private citizens as well as local and state government in making well-informed land use and emergency planning decisions.

The two-color geologic map, at a scale of 1:24,000 (1 inch = 2,000 feet), depicts the geology in greater detail than any previous map, identifying 21 rock units and faults and landslides. A geologic cross section is supplied. An eight-page text discusses rock units and geologic history.

Mapping of this quadrangle in the southern Coast Range represents part of DOGAMI's study of the geology of the Tyee sedimentary basin. This study has brought about a considerable amount of new information, which has given geologists a much better understanding of the stratigraphy of the region. The study is supported by a consortium of nine corporations and agencies from private industry and federal, state, and county government and by the National Geologic Mapping Program (STATEMAP) administered by the U.S. Geological Survey.

To order, see ordering information on the back cover of this issue, or contact the field offices listed on page 122. □

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

Publication title: OREGON GEOLOGY, no. 6000-40; filing date 9-20-94. Published bimonthly, 6 issues per year, annual subscription price \$10. Address of publication office, publisher's business office, editor, and owner: 800 NE Oregon St., # 28, Portland, OR 97232-2162. Publisher and owner: Oregon Department of Geology and Mineral Industries. Editor: Klaus K.E. Neuendorf. Managing editor: Beverly F. Vogt, Publications Manager. No bondholders. Circulation during last 12 months / of single issue, respectively: Net press run 3000 / 3000; paid circulation est. 200 / 200; mail subscription 1411 / 1411; total paid circulation 1611 / 1611; free distribution by mail 168 / 169; free distribution outside the mail 199 / 196; total free distribution 367 / 365; total distribution 1978 / 1976; not distributed 1022 / 1024; return 0 / 0; total 3000 / 3000; percent paid and/or requested circulation 81.4 / 81.5. I certify that all information furnished on this form is true and complete.

Klaus K.E. Neuendorf, Editor

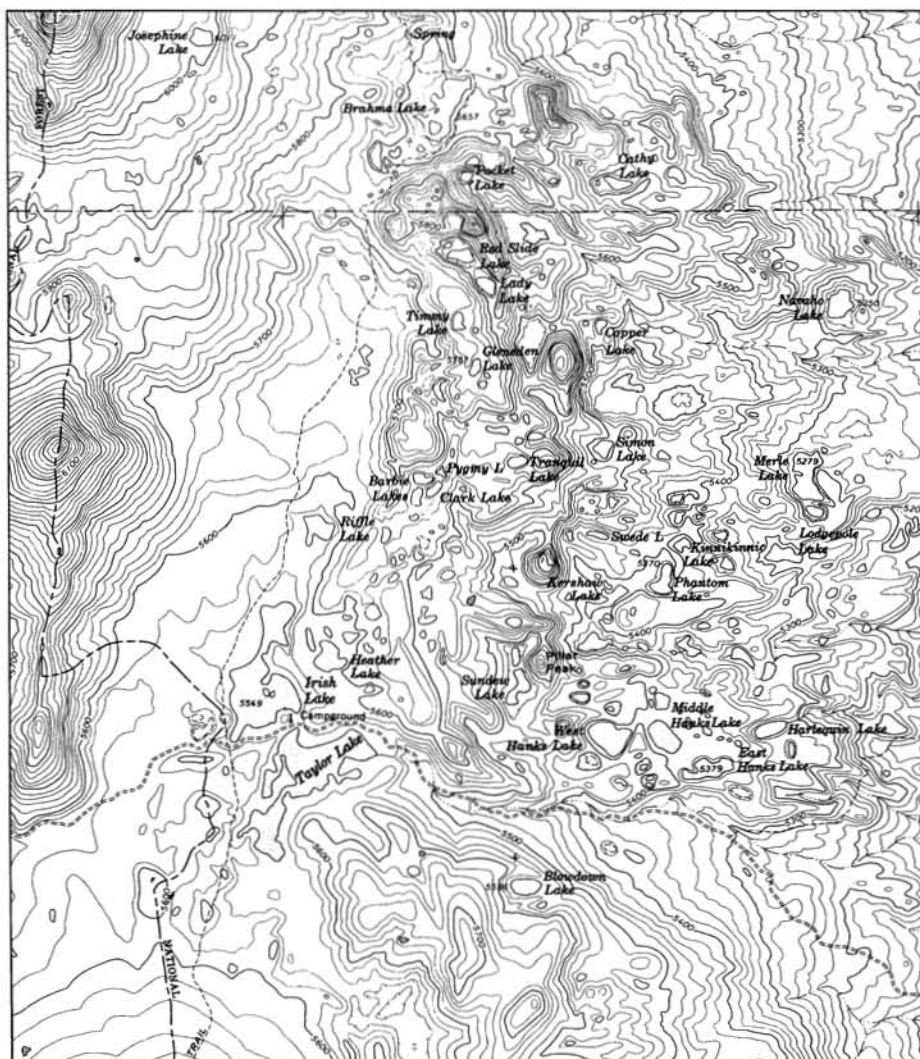
And the winner is . . .

Our photo contest has a winner! Our thanks go to all participants, and we hope it was fun for everybody.

Admittedly, identifying the portion of Oregon shown in the picture was not quite easy, at least the exact identification. Only about 60 percent of the answers were correct. Each participant somehow recognized features typical of the Cascades, but then it took experience with the terrain or thorough map study to locate this lake-studded region. Not many people have had the good fortune to view the Oregon Cascades from the air.

Volcanism and glaciation during the Pleistocene left many lakes of all sizes in several parts of the High Cascades. In fact, one (wrong) guess came as close as the adjacent quadrangle, on the basis that no other area in Oregon had such a lake density. Some participants showed an impressive knowledge of the Cascades. One writer even recognized "the old Forest Service road that winds westerly between the bigger (Irish and Taylor) lakes and eventually (off the picture) ends up at Waldo Lake." Others knew of the South Fork Mackenzie River and the North Fork Willamette River in the valleys on the horizon. The map section below shows the area that makes up the foreground in the photo.

And the winner is—Kyle Gorman of Bend. Congratulations, Kyle! He will donate his prize, the free (two-year) subscription, to the Watermaster's office in Bend.



Central section of Irish Mountain 7½-minute quadrangle, Deschutes and Lane Counties

In memoriam: Bob Bates

Robert Latimer Bates, professor emeritus at Ohio State University, geologist, educator, science writer, and editor, died on June 21 of this year at the age of 82.

Bates wrote *Geology of the Industrial Rocks and Minerals* (1960), which to this day is one of the most important textbooks on the subject. He coauthored *Geology of the Nonmetallics* (1984) and *Industrial Minerals: Geology and World Deposits* (1990, with Peter W. Harben). After his retirement, he took to writing especially for younger people and nonspecialists. He participated in the second and third editions of the *Glossary of Geology* published by the American Geological Institute (AGI). Work for the next edition of the *Glossary* and for a new edition of the U.S. Bureau of Mines *Dictionary of Mining, Mineral, and Related Terms* was underway when he died.

As a specialist in nonmetallic earth materials, Bates regarded his role in founding the Forum on the Geology of Industrial Minerals as his most significant professional accomplishment. After the 25th Forum, which was held in Portland and hosted by the Oregon Department of Geology and Mineral Industries (DOGAMI), he compiled an index to the proceedings of the first 25 meetings that

was published by DOGAMI (Special Paper 24, 1990).

"The Geologic Column," is certainly best known to readers of the AGI magazine *Geotimes*—"probably the most widely read of any contribution to the geologic literature," in the words of one of his colleagues. A selection was published in 1986 under the title *Pandora's Bauxite—The Best of Bates* (reviewed in *Oregon Geology* in the June 1987 issue). When he retired from the column in 1987, in his farewell message he confessed: "We have reported no results of research and pushed back no frontiers of knowledge. We have just been interested in having a good time." However, he had developed and maintained the column successfully as a humorous means to promote good writing. Bates combined this concern effectively with his love of the English language. He is often quoted as having said: "It's been said that language is the only natural resource that can be mined indefinitely without depletion. I enjoy mining it." Hugh Hay-Roe, who participates in continuing the *Geologic Column*, concludes his poem "Owed to Robert L. Bates" in that column (September 1994) with the lines: "For 20 years and more you toiled for geowriting free of argot, cant, and jargon soiled: We owe you, R.L.B." □

Oregon Council of Rock and Mineral Clubs, Inc., 1994 membership list

The Oregon Council of Rock and Mineral Clubs (OCRMC) brings together most rock and mineral clubs in Oregon. It also manages the exhibits in the display case in the State Capitol in Salem, where individual clubs usually take quarterly turns to put up shows. Through the courtesy of the OCRMC, we are able to print the list below. It is alphabetical by city, so that you may more easily find the club you might like to contact in your area.

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B. Jacobs, Secretary, 231-7500

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97502
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Other clubs currently not members

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PO Box 10682, Eugene, OR 97440

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North Lincoln Agate Society
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0901

Oregon Trail Gem and Mineral Society
PO Box 274, Pendleton, OR 97801 □

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