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COVER PHOTO

Oblique aerial photograph of Portland (foreground), Portland Hills (Tualatin Mountains), and Tualatin Valley (behind hills). Article beginning on next page discusses Portland Hills Silt, which once covered much of this area. Copyrighted photograph courtesy Delano Photographics, Inc.

DOGAMI laboratory policy revised

The greatly increased need for systematic rock-chemistry data for Oregon has prompted the Oregon Department of Geology and Mineral Industries to enlarge the scope of its laboratory facilities. The Department lab is managed by Assayer-Spectroscopist Gary Baxter.

Effective January 1, 1981, the Department's revised purposes and procedures include the following:

The laboratory will be primarily research oriented, with the view of providing necessary support for staff geologists in a manner analogous to the library, cartographic, and editorial sections of the Department.

The laboratory is continuing its service to the public on routine assays and analyses, but it can no longer perform the analyses in-house. Instead, gold and silver assays and heavy-metal and other analyses are now being farmed out to commercial labs on an annual-bid basis. The Department performs random quality-control checks and crushing and grinding. A new price list, schedule, and other procedural instructions will be published at a later date.

Departmental lab capabilities continue to be oriented toward fire assay, geochemical analysis of metals, future improvement of geochemical capabilities for soil and rock, and intermediate preparation (grinding, crushing, sectioning) of farmed-out analyses such as XRD, XRF, and IHA. Where appropriate, the Department relies fully on counterpart laboratories, especially for physical testing and complete testing capabilities with regard to gas or water.

Space needs have been accommodated by moving some facilities to the new Department warehouse, including the grinder, crusher, rock cutter, and table space.

Among the benefits of these changes are a better focus of lab work on samples and projects that will lead to increased mineral-resource development in Oregon; improved quality of the existing lab, enabling cleaner conditions and more quality-control efforts for both public and Department sample analyses; better utilization of other labs through improved coordination and sample-preparation capabilities; and reduced competition with private laboratories. □

DOGAMI gets new address

As part of the remodeling program of the State Office Building in Portland, new room numbers have been assigned to the Portland offices of the Oregon Department of Geology and Mineral Industries. The administrative and professional staff, editing, laboratory, and cartography are still in the same offices on the tenth floor, but the new room number is 1005. The Department's library and business office are on the ninth floor in rooms 901 and 906, respectively. The Department's new mailing address is 1005 State Office Building, Portland, Oregon 97201. Our phone number is still the same: (503) 229-5580. □

CONTENTS

The petrology and stratigraphy of the Portland Hills Silt—a Pacific Northwest loess

by Rodney T. Lentz, Bureau of Land Management, P.O. Box 194, Battle Mountain, Nevada 89820

ABSTRACT

This investigation examines the petrology and stratigraphy of the Portland Hills Silt on the basis of field observations and detailed lateral and vertical sampling. The formation is uniform both in texture and composition. The average grain-size distribution indicates 79 percent silt-, 16 percent clay-, and 5 percent sand-sized particles; very poor sorting; and a fine-skewed grain-size distribution. The median grain size fines westward from about 0.041 mm (0.002 in.) near the Portland basin, to 0.022 mm (0.001 in.) on the west slope of the Tualatin Mountains. Quartz and feldspar constitute 35 and 36 percent, respectively, of the total mineral composition. Clay minerals (15 percent), coarse-grained micas (6 percent), rock detritus and volcanic glass (5 percent), and heavy minerals (3 percent) make up lesser quantities. The heavy-mineral suite is composed of hornblende (41 percent), opaques (17 percent), epidote (15 percent), augite (10 percent), a variety of metamorphic species, and very minor hypersthene. The deposit is essentially massive. However, deeper exposures may reveal up to four 2- to 8.5-m (7- to 28-ft)-thick silt units which are tentatively correlated with major glacial deposits of western Washington: the Orting and Struck Drifts and the upper and lower tills of the Salmon Springs Drift. The distributional, textural, and morphological character of the Portland Hills Silt strongly indicates a loessial origin from the sediments of the Columbia River Basin.

INTRODUCTION

The Portland Hills Silt was named by Lowry and Baldwin in 1952. However, the unique formation, a massive, yellowish-brown micaceous silt, was first noted in 1896 by J. S. Diller. It has since been a topic of some puzzlement, much discussion, and a fair share of tempered debate.

Although physical descriptions of the silt are generally in agreement, there is some controversy regarding its origin. The dissonance arises from minor structural and textural details reported in the silt—notably, the presence of bedding and/or scattered pebbles. Depending upon the interpretation of these features, the silt has been variously interpreted as (1) water deposited (Diller, 1896; Libbey, Lowry, and Mason, 1945; Wilkinson, Lowry, and Baldwin, 1946; Lowry and Baldwin, 1952); (2) wind transported (Darton, 1909; Libbey, Lowry, and Mason, 1944; Theisen, 1958; Trimble, 1963; Livingston, 1966; Schlicker and Deacon, 1967) and (3) a combination of fluvial and eolian deposition (Baldwin, 1964; Beaulieu, 1971; Niem and Van Atta, 1973).

The diversity of these theories may be blamed largely upon difficulties inherent in field study. Poor exposure is probably the greatest obstacle facing a field geologist in the Portland area. In addition, other sedimentary formations of very similar texture and composition commonly underlie or overlie the Portland Hills Silt. These include the laterized Helvetia Formation (Schlicker and Deacon, 1967), the Troutdale-equivalent sediments of the Tualatin Valley (Schlicker and Deacon, 1967), and especially the lacustrine Willamette Silt (Allison, 1953). Exposures on steeper slopes may be further confounded by small- or large-scale mass movement. This is especially true on the abrupt eastern flank of the Tualatin Mountains, where the Portland Hills Silt as well as the clayey Helvetia and residual basalt formations are subject to landsliding. Finally, until this study, little was known about the silt's sedimentary structure, texture, composition, and stratigraphic relations.

The following article summarizes a master's thesis designed to obtain the data that were lacking and to resolve the controversy over the origin of the Portland Hills Silt.

LOCATION OF THE STUDY AREA

Although the field investigation for this study included reconnaissance and sampling throughout the Portland-Tualatin Valley region, Oregon and Washington, the major area of sampling and mapping was confined to approximately 230 km^2 (90 mi^2) in the vicinity of the Tualatin Mountains (Figure 1).

METHODS

Two major types of samples, uniform- and variable-depth samples, were collected during the field study. Both types were obtained either by channel sampling from outcrop or by hand augering. In each case, the resulting sample was a composite taken over a 30-cm (1-ft) vertical interval.

Uniform-depth samples were generally taken from unweathered near-surface material between 1.5 and 2.0 m (5 and 7 ft) in depth from throughout the study area. Variable-depth samples were collected at regular intervals to depths of 2 to 14 m (6 to 45 ft) from hand-augered sections and/or key outcrops. Several oriented samples were also obtained for analysis of fabric and sedimentary structures.

Standard techniques were used to obtain the various petrological and granulometric data presented herein.

STRATIGRAPHIC RELATIONSHIPS

The stratigraphic relationships between the Portland Hills Silt and its major boundary formations in the Tualatin Mountains are illustrated in Figures 2 and 3.

Portland Hills Silt overlies the deformed Miocene Columbia River Basalt Group (Trimble, 1963) and the deeply weathered and laterized Helvetia Formation. The silt also overlies quartzite-bearing conglomerate and vitric sandstone of the Troutdale Formation on the eastern flank of the mountains.

Because of poor exposure and the lithologic similarity between the Portland Hills Silt and the Tualatin Valley equivalent of the Troutdale Formation, definite stratigraphic relationships between these units were difficult to establish. However, subsurface data reported by Schlicker and Deacon (1967) indicate that both the Tualatin Valley sediments and the Troutdale Formation proper show analogous stratigraphic relations. It is assumed, therefore, that the Portland Hills Silt unconformably overlies both the Troutdale Formation proper and its Tualatin Valley equivalent.

In the Portland area, late Tertiary volcanic rocks consisting of olivine basalts and pyroclastics were named the Boring Lava

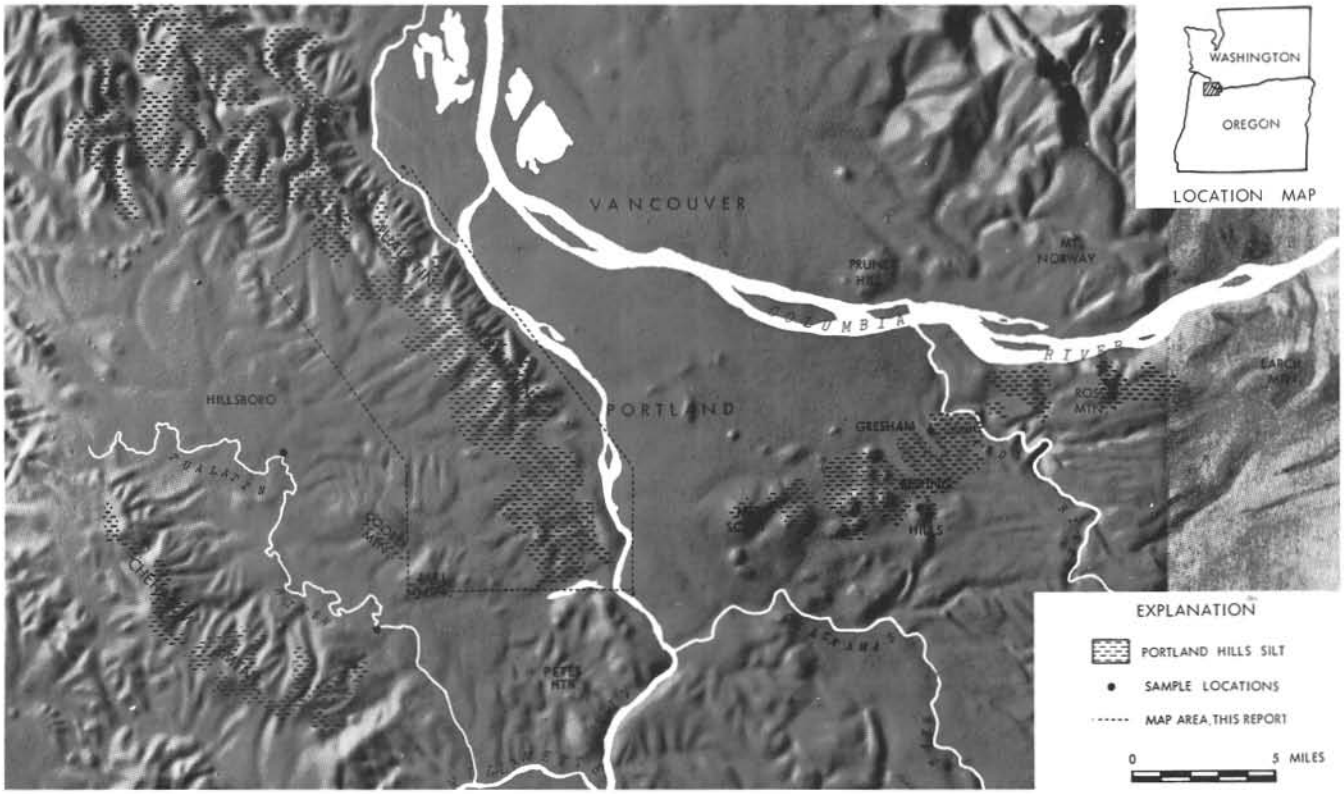


Figure 1. Distribution of the Portland Hills Silt, Portland and vicinity, Oregon and Washington.

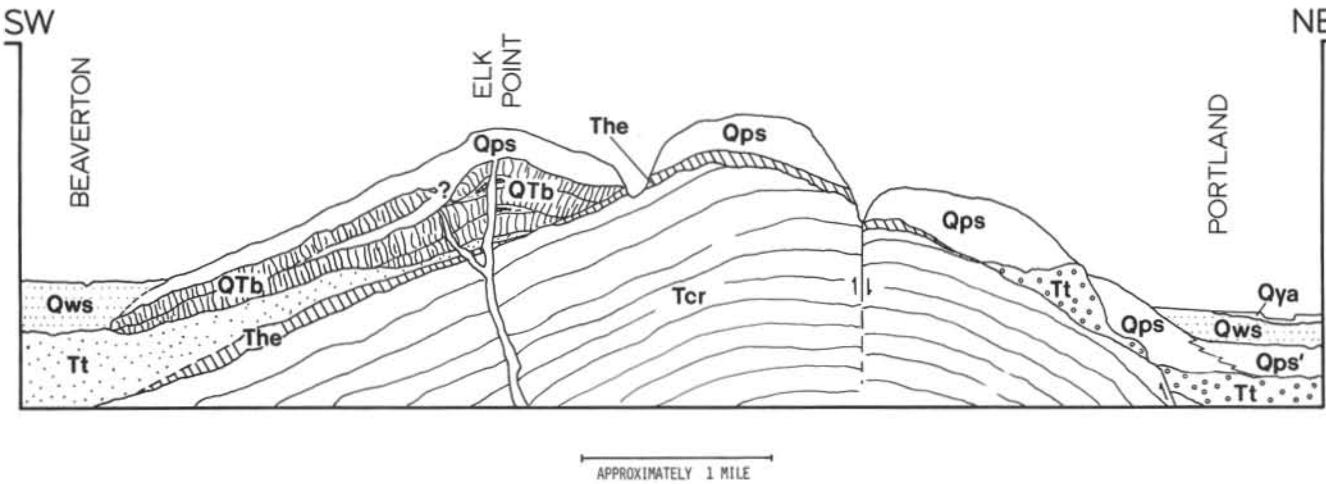
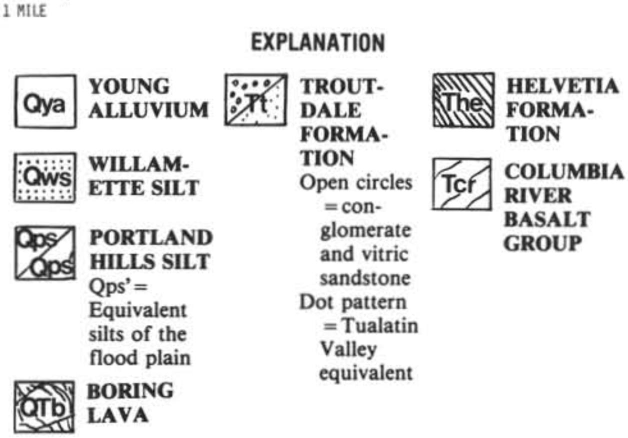


Figure 2. Sketch cross section of the Tualatin Mountains showing surficial stratigraphy. Cross section has extreme vertical exaggeration.



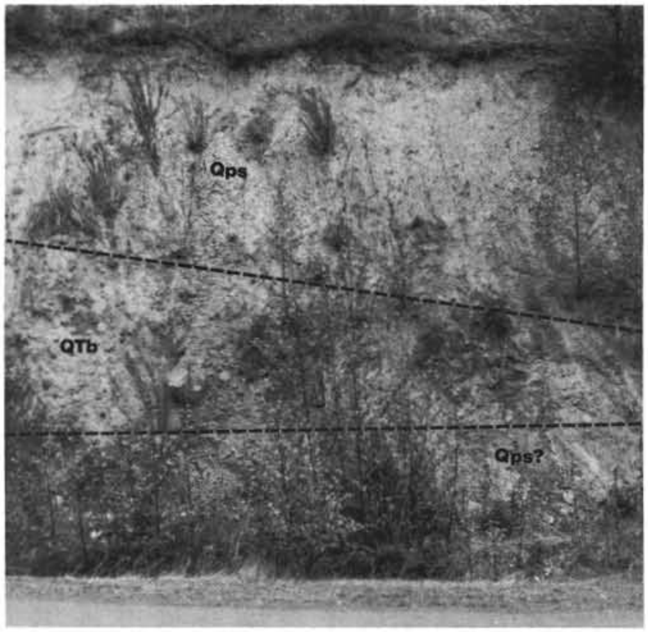


Figure 3. Roadcut showing Boring Lava (QTb) interstratified with the Portland Hills Silt (Qps), near Elk Point, sec. 1, T. 1 S., R. 1 W.

by Treasher (1942). These rocks are, for the most part, older than the Portland Hills Silt. In at least one outcrop, however, the silt appears to be interbedded with the Boring Lava (Figure 3).

The Willamette Silt, named by Allison in 1953, was studied in detail by Glenn (1965). The formation consists chiefly of bedded silts and fine sands which mantle the Willamette and Tualatin Valleys up to elevations of 92 to 107 m (300 to 350 ft). Glenn attributes the origin of these sediments to the ponded waters of unusually large floods similar to the Spokane floods described by Bretz and others (1956).

Because of lithologic and possibly genetic similarities, the stratigraphic relationship between the Portland Hills Silt and the Willamette Silt was of great importance to this study. To examine this relationship, geologic sections were described and sampled from a line of auger holes at various elevations on the western flank of the Tualatin Mountains. One bore hole located at an elevation of 84 m (275 ft), SW¼SW¼ sec. 51, T. 1 N., R. 1 W., confirmed the superposition of the younger Willamette Silt. That section revealed 3 m (10 ft) of Willamette Silt which, in the Tualatin Valley, is characterized by high clay (average 28.7 percent) and low hornblende (average 27.5 percent of heavies) contents (Lentz, 1977). The underlying Portland Hills Silt, however, was distinguished by relatively lower clay (average 18.9 percent) and higher hornblende (average 41 percent of heavies) percentages. Separating the units was an unconformity which was delineated by the oxidized and mottled remnant of a soil profile developed upon the Portland Hills Silt. An increase of organic carbon and concretionary shot below the contact confirmed the presence of a paleosol.

PORTLAND HILLS SILT

Distribution and thickness

Tualatin Mountains: Although the Portland Hills Silt appears to be almost a universal soil constituent throughout the mountains—even residual soils derived from Columbia River basalt or Boring Lava contain tell-tale flecks of mica in their surface horizons—only areas displaying more than 0.5 m (1.6 ft) of material are considered here.

The silt typically mantles flatter ridge crests and slopes above approximately 152 m (500 ft) on the eastern flank of the mountains but locally extends down to between 60 and 92 m (200 and 300 ft) on some spurs. Presumably, remnants of the formation are present even below these elevations where they may or may not be covered by younger alluvium. The silt is present up to 366 m (1,200 ft) on the crest of the mountains. Micaceous sediments of the Portland Hills Silt are more extensive on the broader, western flank of the mountains. However, the abrupt hill slopes and valley walls have been stripped of the deposit. The silt extends down to elevations between 92 and 107 m (300 and 350 ft), where it is generally overlain by Willamette Silt or younger stream alluvium.

Information concerning the total depth of the Portland Hills Silt and its geographic variation is extremely limited, mainly because of the small number of outcrops which expose the base of the formation. Assorted data sources, however, indicate a gross thinning of the deposit westward. The depth of the silt decreases from approximately 37 m (120 ft) on the east side of the Tualatin Mountains to 15 m (50 ft) and less on the western flank (Lentz, 1977).

Outlying areas: Figure 1 shows the areal distribution of the Portland Hills Silt in the greater Portland area. Beyond the Tualatin Mountains, the silt is generally less than 12 m (40 ft) thick and occurs with similar topographic relationships. The deposit thins and finally pinches out in the Chehalem Mountains to the southwest and near Scappoose, Oregon, to the northwest (Theisen, 1958).

Paleosols

The Portland Hills Silt is, in outcrop, essentially massive. Nonetheless, deeper exposures may show up to four thick silt units which are marked by darker, reddish or brownish paleosols (Figure 4). The best example is a 14-m (45-ft)-deep,

Figure 4. Buried soil horizons (dark bands) in the Portland Hills Silt along the Burlington Northern Railroad tracks, secs. 30 and 31, T. 2 N., R. 1 W.

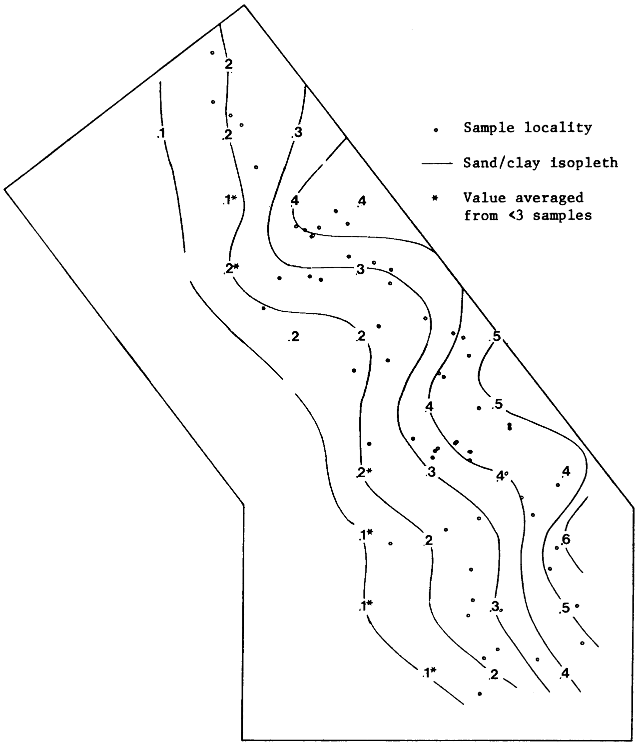


Figure 5. Areal variation of average sand/clay ratios from 67 Portland Hills Silt samples. Area outlined in this map corresponds to study area shown in Figure 1.

auger-supplemented roadcut, located on the crest of the Tualatin Mountains in SW¼SE¼ sec. 23, T. 1 N., R. 1 W. This section displays four silt units which vary in thickness between 2 to 5 m (7 to 16.5 ft). Except within soil profiles (present and buried), the textures and appearances of these beds are very similar. Petrographic analysis, however, does indicate that the surface unit has a higher percentage of hornblende and a lower augite and epidote content than the other three units. These values are substantiated by heavy-mineral analyses of the uniform-depth samples.

When unweathered, the Portland Hills Silt is a light yellowish-brown (10YR6/4-6.5/4). Paleosols in the formation, however, like their modern-day counterparts, are characterized by relatively darker, reddish- or brownish-colored B horizons (10YR6/6-8/5 when dry). The horizons are commonly mottled, showing irregular patches of yellowish-brown and reddish- or rust-orange-stained silt. They frequently show interconnected and, at depth, nearly vertical grayish streaks which represent relict blocky or prismatic jointing. High clay contents (about 25 to 30 percent) and abundant concretionary shot are also typical of these profiles. Though an organic-rich A horizon is rarely preserved in the paleosols, which is typical of buried soils (Yaalon, 1971), organic carbon is often relatively abundant in these zones.

Lateral variation

A distinct fining of the Portland Hills Silt occurs from east to west along the full length of the Tualatin Mountains. Plots of both the phi median and graphic mean (Folk, 1968) reveal a trend toward decreasing grain size from northeast to southwest, approximately perpendicular to the strike of the hills. This trend is confirmed by plotting the sand-to-clay ratios of 67 samples taken from widespread locales throughout the Tualatin Mountains (Figure 5).

Age

The Portland Hills Silt is older than the overlying Willamette Silt and, for the most part, younger than the underlying Boring Lava. Carbon-14 age dates reported by Glenn (1965) indicate a maximum age for the Willamette Silt of about 34,000 years. Trimble (1963) assigned a late Pliocene to late(?) Pleistocene age to the Boring Lava on the basis of stratigraphy. Remanent magnetism of these basalts was recently studied by Burch (1977, personal communication), who found both normal and reversed polarities in samples from the Tualatin Mountains and around the Portland area. Because the Boring Lava is also overlain by the Willamette Silt, and because the Matuyama epoch is the first significant magnetic reversal older than that deposit,[1] these lavas are, in part, probably at least as old, that is, 700,000 years or more.

If the lower portion of the Portland Hills Silt is interbedded with the Boring Lava, it, too, may be as old. Deposition of the loess, then, probably occurred between approximately 34,000 and 700,000 (?) years B.P.

CORRELATION

Quaternary paleosols are generally correlated with intervals of nonglaciation (Ruhe, 1969; Flint, 1971; Yaalon, 1971). For this reason, it is believed that units of the Portland Hills Silt and their associated soils are correlative with glacial stages of the Pacific Northwest. Moreover, the relative thickness and development of the paleosols, as compared to the contemporary soils, suggest more than just incipient or short-term weathering. Individual silt units, then, are probably correlative to the major glacial episodes and their corresponding deposits, while their associated paleosols represent the intervening periods of nonglaciation.

Birkeland and others (1970) summarized the Quaternary stratigraphy of western Washington, indicating four major glacial advances which are younger than 700,000 years but which predate the Olympia interglaciation (beginning 34,000 years B.P.). These are represented by the Orting Drift (650,000 years B.P.), the Stuck Drift (300,000 years B.P.), and the lower (85,000 years B.P.) and the upper (42,000 years B.P.) till of the Salmon Springs Drift. The Portland Hills Silt units described in this paper may be directly correlative with these deposits.

LITHOLOGY

Structure

The Portland Hills Silt is nearly devoid of primary depositional features. Fewer than five percent of the outcrops examined in the Portland-Tualatin Valley region showed any trace of mechanically derived structures. Radiographs of six sedimentary peels and thin silt slabs taken from massive silt confirm these observations.

Finely bedded and laminated zones of very limited vertical and lateral extent are even rarer than outcrops exposing thick bedding and paleosols in the formation. These structures were formed by localized ponding or reworking of the silt by slope wash.

Conversely, diagenetic or epigenetic structures are common in the silt. These include the variably colored shotlike concretions that are 0.5 to 10 mm (0.02 to 0.39 in.) in diameter and the blocky or vertical jointing which are characteristic of

[1] The Blake Reversed Event reported by Smith and Foster (1969) lasted only a very short time, 108,000-114,000 years B.P.

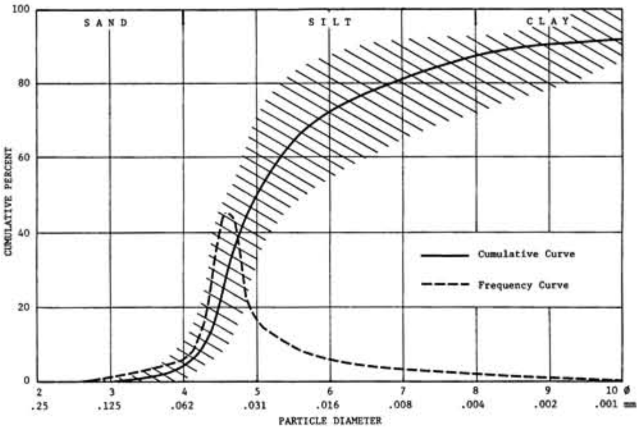


Figure 6. Range of cumulative frequency curves of 20 unweathered Portland Hills Silt samples. Also shown is a typical cumulative frequency curve and its corresponding frequency distribution curve.

the weathering profile of the silt. A few apparently stratified exposures showing fine, reddish-brown banding are present locally. These bands are believed to represent segregations of hydrated iron oxides caused by fluctuations or entrapment of ground water, particularly that associated with landsliding.

Texture

The grain-size distribution in 20 geographically widespread Portland Hills Silt samples is summarized in Figure 6. The shaded area encloses all of the cumulative grain-size curves for these samples. Inspection of individual cumulative curves shows a unimodal distribution for nearly all samples and a very narrow modal range between 4.3 and 4.8 phi in the coarse-silt fraction. The data illustrate a remarkable textural consistency for the Portland Hills Silt throughout the Tualatin Mountains (Figure 7).

Table 1 lists the textural parameters and other characteristics of the 20 samples described above. Folk and Ward textural parameters (Folk, 1968) indicate that the Portland Hills Silt is poorly sorted to very poorly sorted,

Table 1. *Textural data from 20 widespread samples taken at uniform depth from unweathered Portland Hills Silt.*

Textural Parameter	Mean	Range	Standard Deviation
Percent sand	4.88	1.32-11.25	2.28
Percent silt	79.09	68.95-67.73	5.86
Percent clay	16.06	6.47-27.06	6.07
Mode*	4.53	4.3-4.8	0.17
Median	5.12	4.57-5.66	0.31
Folk (1968)			
Mean	5.79	4.80-6.60	0.55
Sorting	1.95	1.13-2.79	0.50
Skewness	0.61	0.52-0.72	0.07
Kurtosis	1.54	0.80-2.30	0.52
Moment measures			
Mean	5.98	5.19-6.67	0.48
Standard deviation	2.27	1.55-2.88	0.39
Skewness	1.64	0.92-2.63	0.45
Kurtosis	5.33	2.81-9.61	1.91

* Determined from cumulative curve.

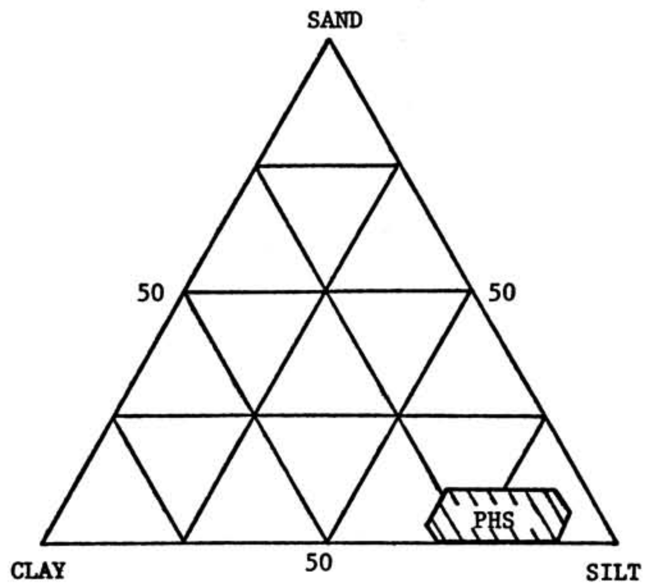


Figure 7. Textural boundaries enclosing 95 percent of all Portland Hills Silt samples. Sand, silt, and clay ranges were derived statistically by adding and subtracting twice the standard deviation from the mean of each.

strongly fine skewed, and very leptokurtic to extremely leptokurtic. The marked peakedness is exemplified by the frequency distribution curve in Figure 8.

Analyses of 47 additional uniform-depth Tualatin Mountain samples were completed to augment those 20 described above. The mean sand, silt, and clay percentages for all 67 samples varied only slightly from the original data, with 4.9 percent sand, 77.2 percent silt, and 18.9 percent clay.

Except for larger (2- to 10-mm [0.08- to 0.4-in.]) concretionary aggregates or shot, coarse material in the Portland Hills Silt is rare. Outsized clasts are believed to represent only extraneous material derived by colluvial or alluvial processes (Trimble, 1963). Contamination most likely occurred during the accumulation of the silt or as the result of post-depositional reworking.

Figure 8. Selected cumulative frequency curves from worldwide loess deposits (Swineford and Frye, 1955; Young, 1967) compared with the curve of a typical Portland Hills Silt sample.

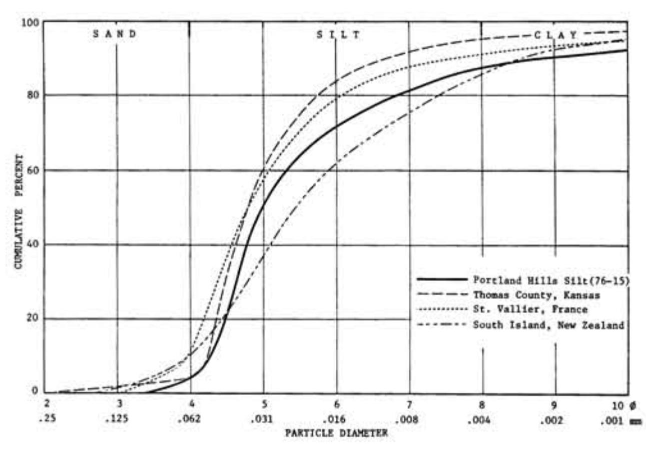


Table 2. *Average percent and grain morphology of light minerals in nine Portland Hills Silt samples.*

Minerals	Average Percent	Shape*	Rounding*	Surface Texture*
Quartz	40.6	eq.-el.	A-sA	fr.
Chert	0.9	eq.	sA-sR	sm.
Alkali feldspar	18.3	eq.-el.	A-sA	etch.
Plagioclase	25.5	eq.-el.	A-sA	etch.
Volcanic glass	2.5	el.	A	sm.
Acid rock fragments	2.8	eq.	sR	sm.-irreg.
Mafic rock fragments	0.2	eq.	sR	sm.-irreg.
Mica group	6.7	platy	sR-R	sm.
Others	2.3	—	—	—

Table 3. *Average percent and grain morphology of heavy minerals in 17 Portland Hills Silt samples.*

Minerals	Average Percent	Shape*	Rounding*	Surface Texture*
Hornblende	40.8	el.	sA-sR	fr.
Lamprobolite	2.8	el.	sA-sR	fr.
Tremolite	1.0	el.	sA-sR	fr.
Actinolite	0.1	el.	sA-sR	fr.-sm.
Augite	9.9	el.-eq.	A-R	etch.-sm.
Hypersthene	0.5	el.	sA-sR	fr.-etch.
Epidote Group	14.9	eq.-el.	sA-sR	etch.-sm.
Garnet	1.4	eq.	sA	sm.
Sphene	0.2	eq.	sR	etch.(?)
Zircon	0.6	eq.-el.	sR-R	pol.
Kyanite	0.3	tabular	sA	sm.
Tourmaline	0.3	el.	sR	pol.
Pyrophyllite	T(?)	—	—	—
Staurolite	0.2	—	—	—
Andalusite	T	—	—	—
Sillimanite	T	el.	sA-sR	sm.
Monazite	0.2	eq.	sR	sm.
Mica Group	3.2	platy	R-wR	sm.
Apatite	0.2	eq.-el.	sR-R	pol.
Hematite	6.4	eq.	R	irreg.
Leucoxene	0.5	eq.	R	irreg.
Magnetite/ilmenite	8.7	eq.	sA-R	sm.-fr.
Rock fragments	2.1	eq.-el.	sR-R	sm.
Volcanic glass	0.5	el.	A	sm.
Others	3.4	—	—	—

* T = trace; eq. = equant; el. = elongate
R = rounded; A = angular; s = sub-; w = well
etch. = etched; fr. = fresh; sm. = smooth; pol. = polished; irreg. = irregular

Fabric

Thin-section studies indicate an apparently random distribution of all particles in the silt, with larger grains being nearly evenly distributed throughout a finer silt and clay matrix. Although elongated grains appear randomly oriented in most views, fabric analysis of three widespread samples shows that the preferred orientation for mica plates is less than 30 degrees from the horizontal.

Particle morphology

Morphological characteristics of individual mineral constituents of the Portland Hills Silt are summarized in Tables 2 and 3. Electron microscopy of quartz grains in the Portland Hills Silt revealed surface textures which are characteristic of glacial or glacial-fluvial environments. These include the more indicative features (Krinsley and Margolis, 1969), which are angularity, extreme relief, and a large variation in size of conchoidal breakage patterns. Textures such as these are typical of loess particles (Cegla and others, 1971) and are very similar to those found in Columbia River sediments (Lentz, 1977).

COMPOSITION

Mineral components

Tables 2 and 3 list the average percentages and grain morphology of light and heavy minerals in the Portland Hills Silt.

Light minerals: Quartz, predominantly as clear, monocrystalline fragments, makes up about 40 percent of the total light-mineral fraction in the Portland Hills Silt. Lesser quantities of plagioclase (An_{10-30}) and alkali feldspars (orthoclase and microcline) combined compose approximately another 40 percent. Minerals of the mica group, acid rock fragments, and volcanic glass constitute successively smaller portions. Carbonates are entirely absent in the formation, even in unoxidized zones or deep auger holes.

Heavy minerals: Grain counts show a strong predominance of blue-green hornblende in the Portland Hills Silt heavy-mineral suite. Less prevalent are, in decreasing order of abundance, the opaque minerals (hematite, magnetite, ilmenite, and leucoxene), epidote-group minerals, augite, mica, lamprobolite, and rock fragments. A variety of metamorphic-mineral species, hypersthene and possibly pyrophyllite, compose between a trace and 2 percent each of the total fraction. Although zoisite and clinozoisite are also present, yellow-green pistacite is the dominant mineral of the epidote group.

Clay minerals: Clay minerals in the Portland Hills Silt were previously studied by A. J. Gude, III (Trimble, 1963). He found kaolinite and illite clay minerals along with another clay which he described as possibly montmorillonite or chlorite.

The present investigation tends to confirm Gude's work. X-ray diffraction studies of three Portland Hills Silt samples indicate the following clay minerals in approximate order of abundance: mixed-layer montmorillonite or montmorillonite, illite, and disordered kaolinite.

Total mineral composition: Total average mineral composition of the Portland Hills Silt was calculated on the assumption that the proportions indicated in the light- and heavy-mineral analyses are roughly constant throughout the coarser part (>0.004 mm [2×10^{-4} in.]) of the size distribution. Based on this assumption, quartz composes almost 35 percent of the total mineral composition. Plagioclase constitutes up to 21 percent, while alkali feldspars and clay minerals total about 15 percent each. Mica-group minerals, rock fragments, volcanic glass, and chert compose approximately 6, 2.5, 2, and 1 percent, respectively. Heavy minerals comprise the remaining 3 percent.

Fossil components

No mega- or microfossils were identified in the Portland Hills Silt at any time during the field or laboratory study. Occasionally, however, somewhat leached terrestrial gastropod shells were discovered in or near the ground surface. Although previously reported in the formation (Wilkinson and others, 1946; Lowry and Baldwin, 1952), diatoms and sponge spicules were not found in the coarse silt and sand fraction (>0.053 mm [0.002 in.]) of any samples studied.

SUMMARY AND CONCLUSIONS

Previous workers (Ruzek and Carpenter, 1922; Treasher, 1942; Wilkinson and others, 1946; Lowry and Baldwin, 1952; Theisen, 1958; Howell, 1962; Trimble, 1963; Schlicker and Deacon, 1967; Beaulieu, 1971) have long presumed that the Portland Hills Silt was derived from the sediments of the adjacent Columbia River basin. The similarities in grain morphology, heavy-mineral components, and their frequencies between the Portland Hills Silt and sediments of the Columbia River substantiate these views.

The present investigation offers data which strongly support a loessial origin for the Portland Hills Silt. As in previous works (Darton, 1909; Theisen, 1958; Trimble, 1963; Schlicker and Deacon, 1967), the concept here is based primarily upon two major aspects of the deposit: (1) its distributional character, and (2) its striking physical resemblance to other loess deposits.

The data clearly establish the massive character and the remarkable uniformity of the deposit both in color and texture, the distinct fining and thinning of the silt from east to west away from the Columbia River source, and the near absence of primary depositional structures and "water-laid" pebbles. Moreover, new data indicate the following additional similarities between the Portland Hills Silt and its loessial counterparts: (1) like surface textures of constituent particles; (2) a marked conformity in grain-size distributions, as illustrated by Figure 8; and (3) the existence and the morphology of paleosols in the silt (Ruhe, 1969).

Dry easterly winds could have easily whipped up glacial outwash silts along the extensive flood plain of the Columbia River valley. Slowed by tree-covered slopes, the wind would then have deposited the dust about the southwestern margin of the broad Portland basin, and, to a lesser extent, upon the adjacent hills north and south of the area now covered by the city of Portland.

During accumulation of the silt, colluvial and alluvial processes would have continued, adding coarser material from older, upslope deposits and locally reworking the silt. At lower elevations, the eolian silt would have become intertongued with water-laid sands and silts of the flood plain (represented as "Qps" in Figure 2). Loess would have collected more rapidly and to greater depths nearest its valley source. A corresponding decrease in grain size would have accompanied the leeward (west) thinning of the deposit.

Though the prevailing surface winds of today are primarily westerly (Highsmith, 1973), thinning and fining of the Portland Hills Silt indicates that easterly or northeasterly winds would have been responsible for its deposition. These may have been the glacially stimulated anticyclones postulated by Theisen (1958), or intense pressure-gradient winds like the easterly winds from the Columbia River Gorge today, or perhaps a combination of these.

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(Continued, bottom of first column, p. 10)

"WELL, THERE GOES THE NEIGHBORHOOD!"

DOGAMI reports on progress of geothermal assessment program

The Oregon Department of Geology and Mineral Industries has released Open-File Report 0-80-14, *Progress Report on Activities of the Low-Temperature Assessment Program 1979-1980*, prepared by Department staff for the U.S. Department of Energy.

The 79-page preliminary report contains summaries of geothermal research activities that were completed through August 1980. These studies are focused on nine areas in the Cascades and central and eastern Oregon: La Grande, Western Snake River Plain, northern Harney Basin, southern Harney Basin, Alvord Desert, Lakeview, Powell Buttes, Belknap-Foley Hot Springs, and Willamette Pass-McCredie Hot Springs. The reports include geologic summaries, geothermal gradient and heat flow data, bibliographies, and listings of the data that will be contained in the final reports.

Detailed, full reports on all areas will be released as open-file reports in stages, beginning in January 1981. They will also contain compilations of geologic data in the form of maps, water chemistry data, temperature gradient measurements, and available geophysical surveys.

Open-File Report 0-80-14 may be purchased for $3.00. Address orders to the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201, or 2033 First Street, Baker, OR 97814. Payment must accompany orders of less than $20.00. □

(Portland Hills Silt, *continued from p. 9***)**

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BLM announces right-of-way regulation that could save money

A little-noticed regulation that went into effect in July 1980 could save money for certain companies and individuals currently using unauthorized rights-of-way.

Gary Rundell, Bureau of Land Management (BLM) realty specialist, said on December 2, 1980 that the regulation provides that certain fees will be waived if an application for the right-of-way is filed with BLM during a four-year grace period that ends in July 1984. Full fees for applications will be charged after that date.

"Normally, a right-of-way applicant would be required to pay all past rental fees for the period of unauthorized use," Rundell said. "The applicant would also have to pay other charges for application processing and construction monitoring."

If the unauthorized right-of-way was in use prior to October 21, 1976, there will be no charges to an applicant for past rental fees and monitoring, Rundell said.

Also, processing fees will not exceed a minimum set by the government, he added. The minimum varies according to the length or size of the right-of-way.

"This amounts to a pardon for qualified unauthorized right-of-way users," Rundell said. "There are thousands of miles of unauthorized rights-of-way in the west. Nationwide, the regulation could save unauthorized users millions of dollars if taken advantage of."

Most of the unauthorized rights-of-way involve communication facilities (radio, television and telephone); power lines; roads, including those across public lands to private residences; and oil, gas, and water pipelines, Rundell said. Others affected by the regulation include reservoirs, canals, ditches, and irrigation pumping facilities. □

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COVER PHOTO

Oblique aerial photograph,looking to the northwest,of the area around Mitchell, north-central Oregon. Cretaceous rocks found here and further to the south and east are discussed in the article beginning on the next page. (Copyrighted photograph courtesy Delano Photographics, Inc.)

DOGAMI releases new publications on Breitenbush Hot Springs and rotation of the Western Cascades of Oregon

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the release of two new publications: Special Paper 9, *Geology of the Breitenbush Hot Springs Quadrangle, Oregon*, by Craig White of Boise State University, and Special Paper 10, *Tectonic Rotation of the Oregon Western Cascades*, by James Magill and Allan Cox of Stanford University.

The Breitenbush Hot Springs area, the subject of Special Paper 9, is a region of recognized high geothermal potential that is currently undergoing cooperative investigation by DOGAMI, private utilities, and industry. The geologic map and 26-page explanatory text of Special Paper 9 will assist in the overall assessment of the resource.

The 67-page Special Paper 10 summarizes current paleomagnetic research in the Western Cascades. Geologists believe that large blocks of the earth's crust have moved in relation to each other. The boundaries between these blocks—or plates—may be regions of significant mineralization and high geothermal potential. The authors of Special Paper 10 postulate that western Oregon and Washington from the Klamath Mountains northward have been affected by plate tectonic motion during the last 50 million years. The movement occurred in two stages, with net clockwise rotation in both stages. Owing to the opening of the Basin and Range, movement in the last 20 million years has produced a net eastward displacement of the Coast Range and Western Cascades block. The eastern boundary of this block may lie beneath the High Cascades, a region of intense volcanism.

The price of Special Paper 9 is $4.00, that of Special Paper 10 is $3.00. Address orders to the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, Oregon 97201. Payment must accompany orders of less than $20.00. □

CONTENTS

A major Cretaceous discontinuity in north-central Oregon

by Greg Wheeler, Geology Department, California State University, Sacramento, California 95819

ABSTRACT

The Cretaceous rocks of north-central Oregon are texturally and compositionally diverse. The Cretaceous rocks found farther to the east are less mature and do not contain the granite and greenstone clasts found in Cretaceous conglomerates near Mitchell, Oregon. The Cretaceous rocks are divided by a major unconformity between the Upper Cretaceous (Turonian) rocks exposed in the eastern outcrop area and the Lower Cretaceous rocks at Mitchell.

DESCRIPTION OF ROCKS

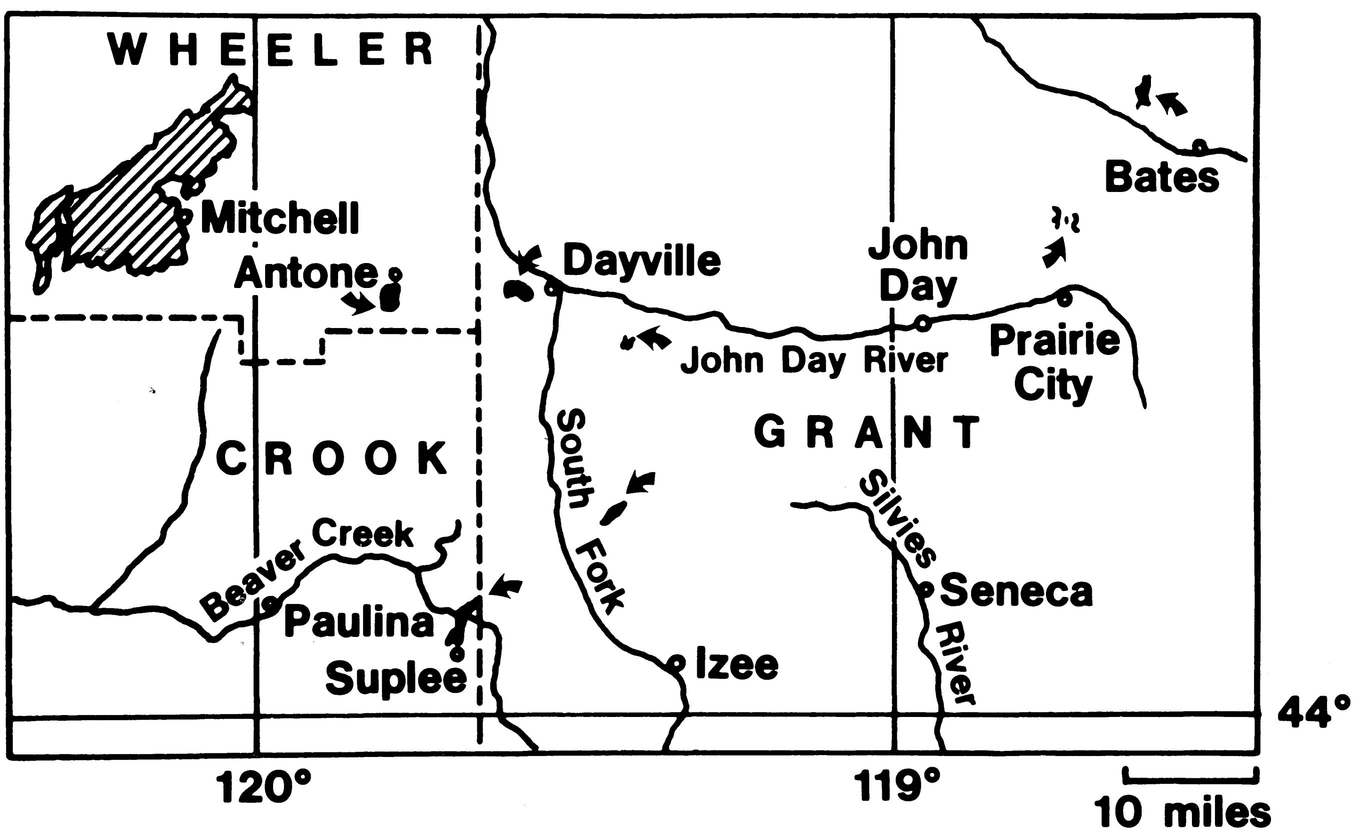
Numerous outcrops of Cretaceous rocks in north-central Oregon have been described by Packard, 1928; Popenoe and others, 1960; Wilkinson and Oles, 1968; Oles and Enlows, 1971; Dickinson and others, 1976; Wheeler, 1976; Mullen, 1978. Exposures of these rocks generally encompass only 2 to 10 km^2; however, Cretaceous rocks covering 125 km^2 crop out in the Mitchell quadrangle near Mitchell, Oregon (Figure 1).

The Cretaceous rocks in the Mitchell quadrangle are exposed in the core of the Mitchell anticline. The rocks are divided into two main map units on the basis of lithology. The shale lithology is named the Hudspeth Formation (Figure 2), and the intertonguing conglomerate unit is named the Gable Creek Formation (Wilkinson and Oles, 1968, p. 133) (Figure 3). The Gable Creek Formation is described by Oles and Enlows (1971, p. 11) as containing clasts that are "rounded to subrounded, ranging in size from small pebbles to boulders," most commonly including "chert, quartzite, and granitic rocks," and minor amounts of "vein quartz, phyllite, greenstone, mafic volcanics, and sandstone." The cementing agent is calcite.

Cretaceous beds at Antone, Dayville, and north of Suplee in the Dayville quadrangle; north of Deer Creek in the Izee quadrangle; and along Dixie and Windlass Creeks in the Bates quadrangle are lithologically distinct from those further west at Mitchell. The most abundant rock type is sharpstone conglomerate with clasts 1 to 4 cm in size and a fine-grained groundmass. Medium- to fine-grained sandstone makes up 30 percent of the unit and shale and breccia less than 5 percent each. A typical hand specimen of sharpstone conglomerate contains 50 percent chert. The abundance of chert produces a rough, knobby surface, with clasts 2 to 4 cm in diameter protruding from a surface of less resistant groundmass and shale clasts. Red chert is the most angular type but is less common than grey, brown, and buff chert clasts, which are more rounded and usually larger.

Quartz, mostly as clear, rounded individual grains, makes up 25 percent of the rock. Some quartz grains are 0.5 mm in diameter, but most are somewhat smaller. The clarity and size of these quartz grains indicate a coarse-grained plutonic or

Figure 1. Index map of north-central Oregon showing location of Cretaceous outcrops. Lined pattern represents Lower Cretaceous (Albian-Cenomanian) rock outcrops. Arrows point to solid black areas that represent Upper Cretaceous (Turonian) rock outcrops.



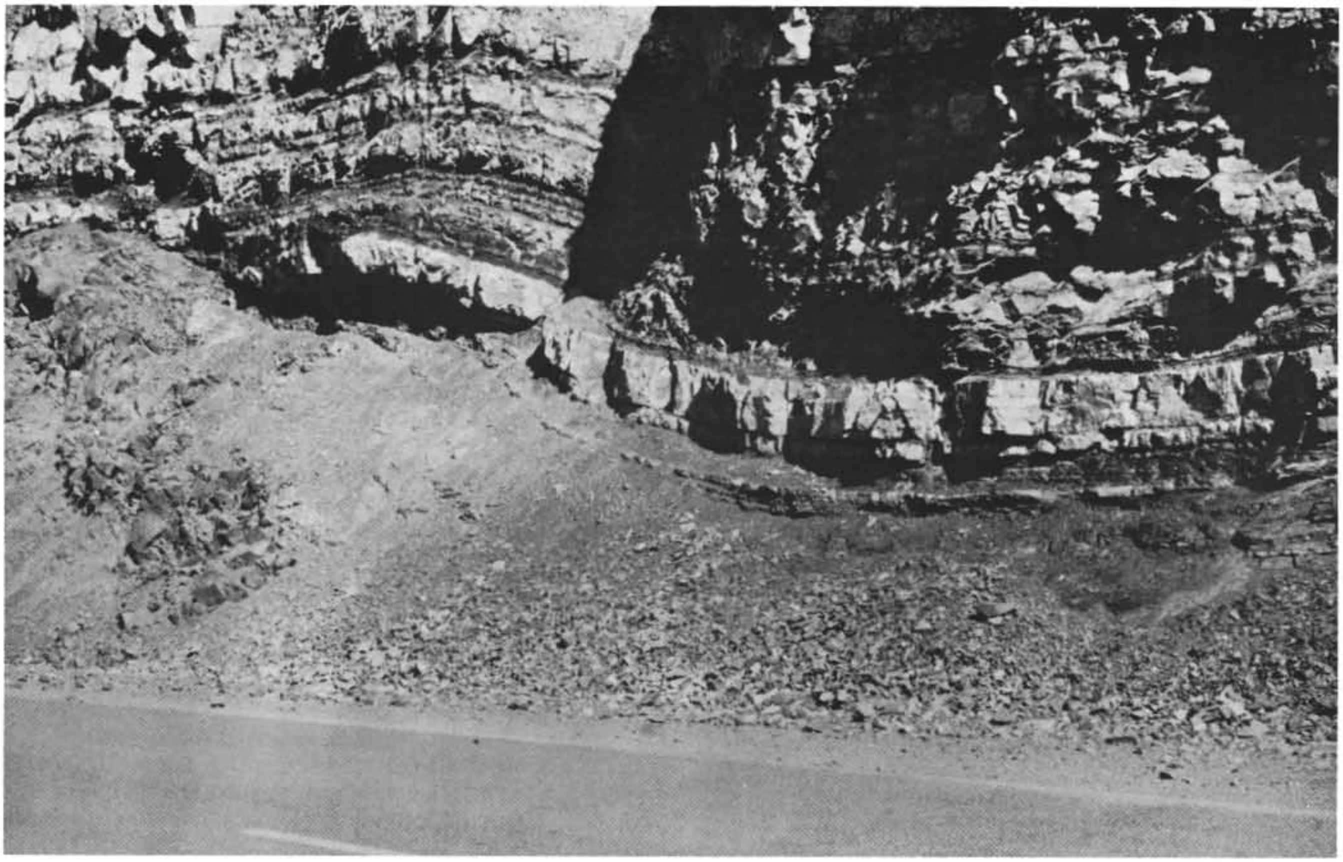


Figure 2. Fault offset in bedded shale and sandstone of Hudspeth Formation just east of Ochoco Summit on U.S. Highway 26.

vein source. A few quartz crystals have resorbed margins and remnant bipyramidal shape indicative of volcanic quartz. Quartzite clasts present in some thin sections indicate that a sedimentary source also donated quartz to the depositional basin. The remaining 20 to 25 percent of the sharpstone conglomerate is made up of fine-grained sand and siltstone clasts. The siltstone clasts, which have indistinct boundaries with the sandy matrix, appear to be "rip-up" clasts from the finer-grained beds. Greenstone clasts are present but are quite rare in most outcrops.

The finer grains have essentially the same composition as the coarser material, except that the quartz content increases relative to chert as grain size decreases. The roundness of the quartz decreases, and the sphericity increases in the finest grained sediment.

As the sharpstone conglomerate grades into breccia, the amount of sandy matrix decreases. Some parts of the rock are calcareous, but calcite is not a common cement either in the coarse or fine samples.

Graded bedding is common but usually indistinct. Most sharpstone conglomerate beds contain shale clasts in distinct layers a few centimeters thick. Cross-bedding is present in a few of the sandstone outcrops. The matrix is often stained with limonite.

The sharpstone conglomerate is well represented on the ridge east of Windlass Creek in secs. 26, 27, 34, and 35, T. 10 S., R. 34 E., northwest of Bates, Oregon. These rocks form prominent, chocolate-brown weathered outcrops enclosed in deep regolith. Freshly broken surfaces are yellow-brown.

In contrast to the Cretaceous rocks of the Mitchell area, rocks in the areas farther to the east contain no granitic and only a few greenstone clasts. Much less chert is found in the Gable Creek Formation than in conglomerates to the east. The presence of shale clasts, angularity of all clasts, and poor sorting indicate that the Cretaceous rocks in the Dayville, Izee, and Bates quadrangles are texturally less mature than the western rocks. The compositional and textural differences of the eastern Cretaceous rocks may be partly due to their proximity to pre-Tertiary rocks in the Blue Mountain uplift that may be the common source of north-central Oregon Cretaceous rocks (Wheeler, 1976, p. 31).

AGE OF ROCKS

The Hudspeth and Gable Creek Formations and Cretaceous rocks farther to the east rest unconformably on older rocks. The Bates rocks rest on a Jurassic-Cretaceous pluton. Those in the Dayville and Izee quadrangles overlie sedimentary and metasedimentary rocks which are Jurassic and older.

Fossils such as ammonites in the Hudspeth Formation and a few pelecypods in the upper Gable Creek Formation led Wilkinson and Oles (1968, p. 135, 136) to conclude that these rocks range from early to late Albian. Later, the age of these beds was extended to include the Cenomanian (Oles and Enlows, 1971, p. 11). The only other early Cretaceous beds in eastern Oregon are Albian in age; they contain *Tempskya* sp. fern and are located near Greenhorn, Oregon (Ash and Read, 1976).

Popenoe and others (1960, p. 1531-1532) consider the eastern Cretaceous rocks as Cenomanian or possibly lower Turonian, based on a "fairly large molluscan fauna." Although the molluscan species are generally considered Cenomanian, all but the subgenus *Pseudouhligella* are known in younger rocks. Fossils collected along Dixie Creek in the southern half of the Bates quadrangle by Mobley (1956) were identified by John Reeside as "Upper Cretaceous, probably Turonian, and equivalent in age to the Chico Formation of California" (Mobley, 1956, p. 39).

CONCLUSION

Peterson (1967) recognized an Upper Cretaceous stratigraphic discontinuity in northern California and southwestern Oregon. This unconformity, which is sub-Turonian in age, underlies the type Chico (Peterson, 1967, p. 567), and its existence beneath the rocks of Turonian or "Chico" age in north-central Oregon would explain the lithologic and age variations discussed. The Gable Creek and Hudspeth Formations are below the unconformity, while the Cretaceous rocks in the Bates quadrangle are clearly above. The Dayville and Izee quadrangle rocks are lithologically similar to those at Bates, and fossil evidence permits their placement above the sub-Turonian unconformity. The age assignment and lithology of conglomerates near Greenhorn indicate that these conglomerates represent rocks below the unconformity.

Figure 3. Gable Creek Formation, near Mitchell.(Oles and Enlows, 1971).

The broad regional extent of this discontinuity may be a result of the Coast Range Orogeny suggested by Irwin (1964). Recently developed plate tectonic models (Avé Lallemant and others, 1980) do not easily explain such a wide-spread unconformity. Whatever the origin, recognition of this major unconformity is essential in assembly of the Cretaceous history in Oregon.

ACKNOWLEDGMENTS

Part of the field work upon which this paper is based was supported by a Geological Society of America Penrose Grant in 1971 and 1973 and by the Oregon Department of Geology and Mineral Industries. The manuscript was critically reviewed by D. McGeary.

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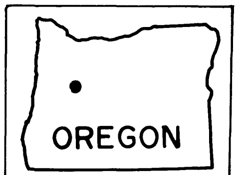
Geology and mineral deposits of the Quartzville mining district, Linn County, Oregon*

*by Steven R. Munts, Geologist, U.S. Bureau of Mines, E. 360 Third Avenue, Spokane, Washington 99202**

The Quartzville district, located in the Western Cascade Range, Linn County, Oregon, has produced an estimated $300,000 to $800,000 worth of metals, primarily gold and silver, since 1861. Production has occurred from both lode and placer deposits.



Location Map

Bed rock consists in part of the Tertiary Sardine Formation. This calc-alkaline suite is composed of a sequence of basalt, andesite, and dacite, overlain by intermediate to felsic interstratified flows and pyroclastic units. Also included are flows of dacite, rhyolite, and rhyodacite, as well as ash flow tuff and multilithic volcanic breccias. Together, these lithologies display multiple depositional cycles of basic to intermediate or intermediate to felsic rocks, each successive cycle more felsic than the last.

The only major fold in the area is the Sardine Syncline. Local steep dips of beds near small plugs and arcuate faults are interpreted to be related to subvolcanic magmatism and subsidence, respectively. Local unconformities are present.

Felsic plutons of probable Miocene age intrude the volcanic pile. The more than ten small plugs present consist of diorite, quartz diorite, granodiorite, quartz monzonite, and felsic aplite. The most felsic plugs occur in the most intensely mineralized central portion of the district.

The Quartzville district appears to be on the eastern edge of a volcanic complex. Evidence includes (1) variations in thicknesses of regional lava and pyroclastic flows, (2) flow directions, and (3) clast-size gradations in pyroclastic deposits. Flow lithology, dikes terminating in flows, plutonic rocks, mafic plugs, dike swarms, ignimbrites, vitrophyre dikes, tuff dikes terminating in ash flow deposits, diorite sills, and arcuate structures are other volcanic-plutonic features.

Vein-type mineralization is widespread primarily in the volcanic rocks, although plutonic dikes often parallel veins or form one wall of a vein. Gold has been the most valuable metal produced to date; veins also contain copper, lead, and zinc sulfides at depth. Associated gangue minerals include quartz, calcite, barite, stibnite, and pyrite. The veins display two prominent trends, N. 20° W. and N. 45° W. The most intense mineralization occurs sporadically above the most silicic plutonic rocks, near to silicic volcanic rocks, and near the most intense alteration.

At least two tourmaline breccia pipes and three tabular tourmaline breccia zones formed contemporaneously with vein mineralization. The pipes are ellipsoidal to circular in shape and vary in size from 2 to 30 m (7 to 100 ft) in diameter. The clasts display varied volcanic and plutonic lithologies with varied types of alteration. Breccia zone clasts are derived from local country rock. Country rock and some clasts may be partly or completely replaced by a tourmaline-silica ± sericite-pyrite assemblage. An admixture of quartz ± clay, tourmaline, and pyrite cements the breccias. The large pipe grades upward into a shatter breccia of highly fractured rock with minor displacement, and both pipes are interpreted to have formed by solution collapse.

Propylitic alteration is widespread throughout the district in both volcanic and plutonic lithologies. Argillic and quartz-sericite alteration locally occurs as concentric zones in the Dry Gulch area. Here, too, both volcanic and plutonic lithologies are affected.

Zonation is also evident in volcanic and plutonic lithologies, gangue minerals, and laterally zoned ore minerals. Abundances of trace elements in volcanic and plutonic host rocks indicate a distinct zonation of base metals. Precious metals also appear to be zoned. Anomalously high concentrations of lead, zinc, and copper occur progressively inward toward Dry Gulch. Anomalous molybdenum occurs interior to some copper anomalies and near several gold anomalies. This zonation is crudely centered upon the phyllic alteration zone.

Hydrothermal alteration and mineralization of the district are related to the plutonic-volcanic complex. Evidence includes the close association of all Western Cascades mineral districts with felsic intrusives, chemical and mineral (ore and gangue) zonation within the districts, proximity to felsic vent volcanic rocks, and structural features related to these intrusions. Geologic and geochemical evidence implies that only the higher levels of the hydrothermal system are exposed. Evidence includes alteration patterns, breccia pipes and dikes, and mineral (ore and gangue) and trace element zonation. Implied is the possible existence of porphyry-type mineralization at depth, with a possible near-surface limonite-precious metal oxide cap. □

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* This article summarizes work done for a University of Oregon master's thesis entitled "Geology and Mineral Deposits of the Quartzville Mining District, Linn County, Oregon" (1978).

New USGS open-file reports released

The following open-file reports that may be of interest to our readers have been released by the U.S. Geological Survey. They are available for inspection at the library of the Oregon Department of Geology and Mineral Industries, on the ninth floor, State Office Building, Portland, or may be purchased for the indicated prices from the Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, Colorado 80225; phone (303) 234-5888.

79-1691 — Seismic studies at the Mt. Hood volcano, northern Cascade Range, Oregon: by S.M. Green, C.S. Weaver, and H.M. Iyer; 40 p.; price — fiche $3.50, paper $5.00.

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80-490 — Geothermal resources and conflicting concerns in the Alvord Valley, Oregon: by C.E. Wassinger and D.M. Koza; 22 p.; price — fiche $3.50, paper $3.00.

80-521 — Lithologic log of drill cuttings for DOGAMI heat flow hole CR-SB, Mount Hood, Oregon: by K.E. Bargar; 10 p.; price — fiche $3.50, paper $1.25.

80-532 — Preliminary report on the Lakeview uranium area, Lake County, Oregon; by G.W. Walker; 59 p., 2 over-size sheets, scale 1:48,000; price — fiche $4.50, paper $13.00.

80-593 — Mount St. Helens ash fall in the Bull Run watershed, Oregon, May-June 1980: by M.V. Shulters and D.G. Clifton; 11 p.; price — fiche $3.50, paper $1.75.

80-625 — Proceedings of Conference IX: Magnitude of deviatoric stress in the Earth's crust and upper mantle: by J.F. Evernden, convener; 1010 p., in 2 volumes; price — fiche $3.50, paper $131.25.

80-645 — Outer Continental Shelf oil and gas activities in the Pacific (southern California) and their onshore impacts: A summary report, May 1980: by G.S. Macpherson and J. Bernstein; 134 p.; price not yet released.

80-737 — Chemical and isotopic data for water from thermal springs and wells of Oregon: by R.H. Mariner, J.R. Swanson, G.J. Orris, T.S. Presser, and W.C. Evans; 50 p.; price not yet released.

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80-839 — Geochemical data for rock, stream sediment, and panned concentrate samples, Mount Hood Wilderness Area, Oregon: by T.E.C. Keith, M.H. Beeson, K.E. Bargar, and S.P. Marsh; 12 p., 5 tables, location map, scale 1:62,500; price — fiche $4.00, paper $7.00.

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80-891 — Volcanic stratigraphy and alteration mineralogy of drill cuttings from EWEB 4 drill hole, Clackamas County, Oregon: by T.E.C. Keith and J.R. Boden; 9 p.; price — fiche $3.50, paper $1.00. □

80-1243 — Geology of the igneous complex at Tincup Peak, Kalmiopsis Wilderness Area, southwestern Oregon: by F. Gray; 72 p., map, scale 1:12,000; price not yet released. □

Oregon's southernmost glacier named for hypothermia expert

On October 2, 1966, Theodore G. Lathrop, Oregon City physician, well-known expert on hypothermia, and author of the book *Hypothermia—Killer of the Unprepared*, looked down from the summit of Mt. Thielsen, which he had just climbed, and spotted a snow field on the precipitous North Face. Noting two horizontal parallel cracks on the snow field, he began to wonder if it might actually be a glacier that had never been reported before. Later investigations proved he was correct, making this glacier, located on Mt. Thielsen 77 mi north of the California border, Oregon's southernmost glacier.

The ice mass is on the north side of the mountain and owes its continuing existence to the fact that it is protected from the sun by the shadow of the mountain and fallen debris from the main spire. Following Lathrop's discovery, small parties, often including Lathrop's nephew Ralph H. Nafziger, visited the glacier nearly every year to measure and observe it, publishing their findings in the papers listed at the end of this article.

Ted Lathrop died May 29, 1979, at the age of 65. On June 21, 1980, at the suggestion of Nafziger, Leonard Delano proposed to the Oregon Board of Geographic Names that the glacier be named after Lathrop. The Board approved the name and forwarded it to the U.S. Geological Survey, who have since confirmed it. Future USGS topographic maps will use the new name of Lathrop Glacier.

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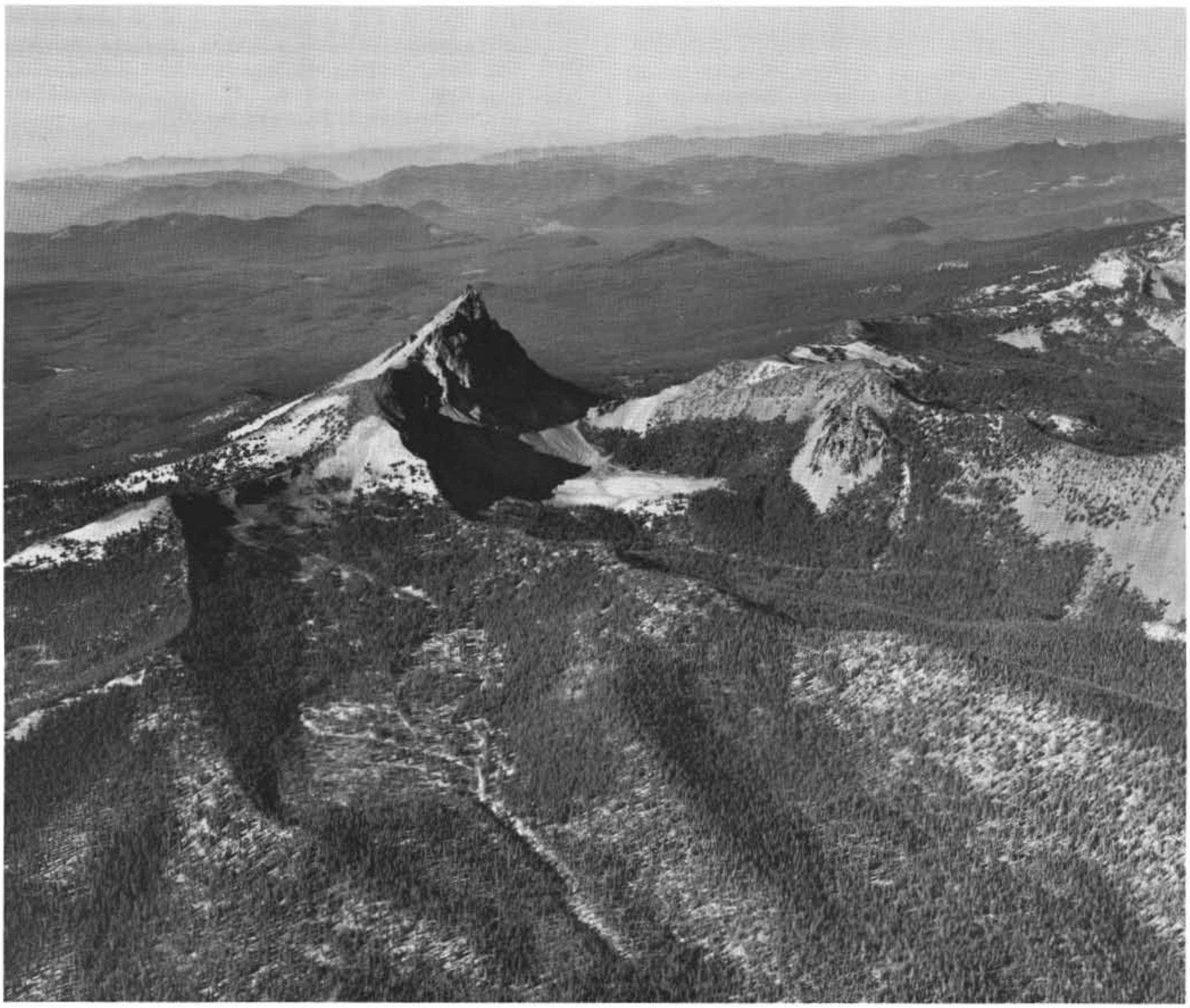
Northeast side of Mt. Thielsen, elevation 9,173 ft, which lies on the line between Klamath and Douglas Counties in southern Oregon. Newly named Lathrop Glacier is in the shadows on the extensively glaciated north face of the mountain. (Copyrighted photograph courtesy Delano Photographics, Inc.)



Oil and gas exploration spreading to other parts of state

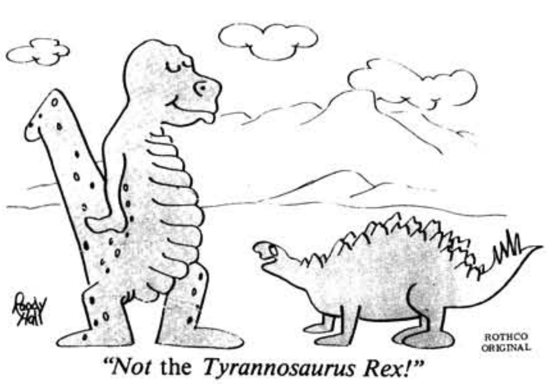
The Oregon Department of Geology and Mineral Industries has issued twelve oil and gas drilling permits since August 1980. Exploration interest has spread from Columbia County and the surrounding area, which accounted for only a third of the recent applications. The Willamette Valley, Lincoln County on the coast, and Crook County in central Oregon were the sites of the remaining applications. The table below lists the recent permits issued.

The March 1981 issue of *Oregon Geology* will contain a summary of the 1980 drilling and production activity.

Table 1. *Oil and gas drilling permits issued since August 1980*

Permit number	Date issued	Company	Lease name	Location
164	9/5/80	American Quasar Petroleum Co.	Investment Management 20-21	NW¼ sec. 20 T. 6 N., R. 4 W. Columbia County
165	9/11/80	American Quasar Petroleum Co.	Wilna, Inc., et al. 6-43	SE¼ sec. 6 T. 6 N., R. 4 W. Columbia County
166	9/22/80	Texaco, Inc.	USL-OR 17-1	NE¼ sec. 17 T. 19 S., R. 20 E. Crook County
167	9/23/80	Ehrens Petroleum and Development Co.	Longview Fibre 1	NE¼ sec. 20 T. 9 S., R. 11 W. Lincoln County
168	9/23/80	Ehrens Petroleum and Development Co.	Longview Fibre 2	NE¼ sec. 28 T. 9 S., R. 11 W. Lincoln County
169	10/15/80	Reichhold Energy Corp.	Columbia County 14-34	SW¼ sec. 34 T. 7 N., R. 5 W. Columbia County
170	10/3/80	Quintana Petroleum Corp.	Watzek et al. 30-1	NW¼ sec. 30 T. 6 N., R. 6 W. Clatsop County
171	11/7/80	John T. Miller	Bork 1	SE¼ sec. 26 T. 8 S., R. 5 W. Polk County
172	11/14/80	American Quasar Petroleum Co.	Hickey 9-12	NW¼ sec. 9 T. 12 S., R. 2 W. Linn County
173	11/14/80	American Quasar Petroleum Co.	Henschel 17-34	SE¼ sec. 17 T. 10 S., R. 3 W. Linn County
174	11/14/80	American Quasar Petroleum Co.	M and P Farms	SW¼ sec. 33 T. 11 S., R. 4 W. Linn County
175	11/18/80	American Quasar Petroleum Co.	Wilna et al. 5-23	SW¼ sec. 5 T. 6 N., R. 4 W. Columbia County

□



"Not the *Tyrannosaurus Rex!"*

Correction

Part of the Tualatin River was in the wrong location in Figure 1, page 4, in the January 1981 issue of *Oregon Geology*. The course of the river should have continued more to the east, entering the Willamette River from north of Petes Mountain. Our thanks to the several eagle-eyed readers who called this error to our attention.

Smithson said, "You know, one pebble moving a foot in two million years is enough action to keep me really excited."

Ewart M. Baldwin retires

A professional comment...

Over 60 alumni, faculty, and friends attended a retirement dinner for Ewart and Margaret Baldwin in Eugene, Oregon, on December 8, 1980. Widely known around the Pacific Northwest for his contributions to Oregon geology, Professor Baldwin retired at the end of 1980 after 33 years at the University of Oregon.

Baldwin received his B.S. and M.S. degrees in geology from Washington State University and his Ph.D. from Cornell. In 1943, he returned to the Pacific Northwest and worked for the next four years with the Oregon Department of Geology and Mineral Industries in Portland, starting first with a study of the geology and coal resources of the Coos Bay area. As he himself said, "When I first came to Oregon to work on the Coos Bay coal formations, I looked in all the mines and mapped the coal beds." That work initiated his interest in the geology of the entire state.

In 1947, Baldwin joined the staff of the University of Oregon and began a long project of mapping the Coast Range, particularly in Coos County. He also began teaching his Geology of Oregon courses, which he later used as a basis for his book, *Geology of Oregon*, now in its third edition.

Several of Ewart's colleagues and friends spoke at the retirement dinner. Gifts presented to him during the evening included a framed stratigraphic column from Wil and Joyce Eaton with each bed bearing a well-known "Baldwinism," a bound volume of letters with tributes from faculty and alumni, and a grandfather clock with a plaque inscribed, "Presented to Ewart Baldwin by faculty, alumni, and friends in appreciation of a career devoted to the Department of Geology and students at the University of Oregon."

Ewart responded warmly and expressed his pleasure at seeing so many old friends who had traveled many miles to be present. He stated that although he plans to keep up his contact with the University and to continue his interest in Oregon geology, he and Margaret also expect to travel extensively, with Europe, China, New Zealand, and Africa high on the list. His immediate move is not so far afield, however, for he will teach for one year at Whitman College in Walla Walla, Washington, as Arnold Professor of Geology.

The evening ended as it had begun, with people circulating informally from group to group around the banquet hall, reminiscing and generally enjoying the opportunity to get together and reflect upon the fruitful career of a well-loved friend and colleague. There was no sadness, for we all felt confident that this was only a milestone in a scholarly career which would extend well into the future.

—Norman F. Savage, Professor of Geology
University of Oregon, Eugene, Oregon

A personal comment...

The soft rocks of Oregon will be able to sleep better at nights now that Ewart Baldwin has retired. All those rocks won't be hammered on with his G-pick, given names and ages, and assigned a color on a map. After 37 years of tramping up every major—and many a minor—watercourse on the west side of the Cascades, after slogging through the brush of the heavily vegetated hillsides that obscure so much of the geology of Oregon's Coast Range, Dr. Baldwin is taking off his field boots. And Professor Baldwin has given his last lecture and

Baldwin at his retirement dinner.

posted the final grades for his last classes at the University of Oregon.

During his 33 years at the University of Oregon, Baldwin was famous for his Geology of Oregon classes—and for both his formal and his informal field trips, which he dearly loved to lead. In fact, the lure of a field trip was so strong that he rarely considered the weather. A normal rainy day was rated as "good," and the dry ones were either "salubrious" or "bodacious," the latter term usually referring to a trip replete with flat tires, missed turns, bad roads, downed trees, and low water bridges under high water conditions.

During the summers, Baldwin habitually headed for the Coast Range, where he mapped the poorly exposed geology. Some of the work was in cooperation with the U.S. Geological Survey and some with the Oregon Department of Geology and Mineral Industries. Teaching and turning out numerous maps and publications on the geology of western Oregon was not enough to keep him occupied, and in 1964 he produced the much-needed *Geology of Oregon*, which he continued to revise as new information came along. His latest revision came off the press just as he was giving his final exam at his last class at the U. of O. and will be reviewed in an upcoming issue of *Oregon Geology*.

Professorial sabbaticals come and go, and Ewart Baldwin always went. His lectures have literally been heard around the world, not once but repeatedly, for he and his wife Margaret have gone on several floating campus cruises where he lectured and she served as librarian. Other trips have taken them to most of the far corners of the world, and not surprisingly, the Baldwins have plans for more travel.

Baldwin's ability to dredge up names, dates, and past events has always been a source of wonder to his many friends scattered over the West. He is also well known to both friends and students for his flow of epigrams, snatches of quotations, and bits of poetry which he releases at appropriate moments. He is an outstanding teacher; perhaps the most telling tribute of his impact on his students came from one of them who said that of all his professors Dr. Baldwin was the only one who was willing to share his understanding of a problem with him and to outline exactly how he had arrived at his conclusions.

Indeed, Baldwin's contributions to Oregon's geology have been many. We suspect, too, that after a bit of teaching and traveling, he will be back to do more geologizing—perhaps returning to some as yet unmapped area to awaken a few more of those soft rocks from their long sleep with his hammer.

—Ralph S. Mason, Retired State Geologist
Oregon Department of Geology and Mineral Industries □

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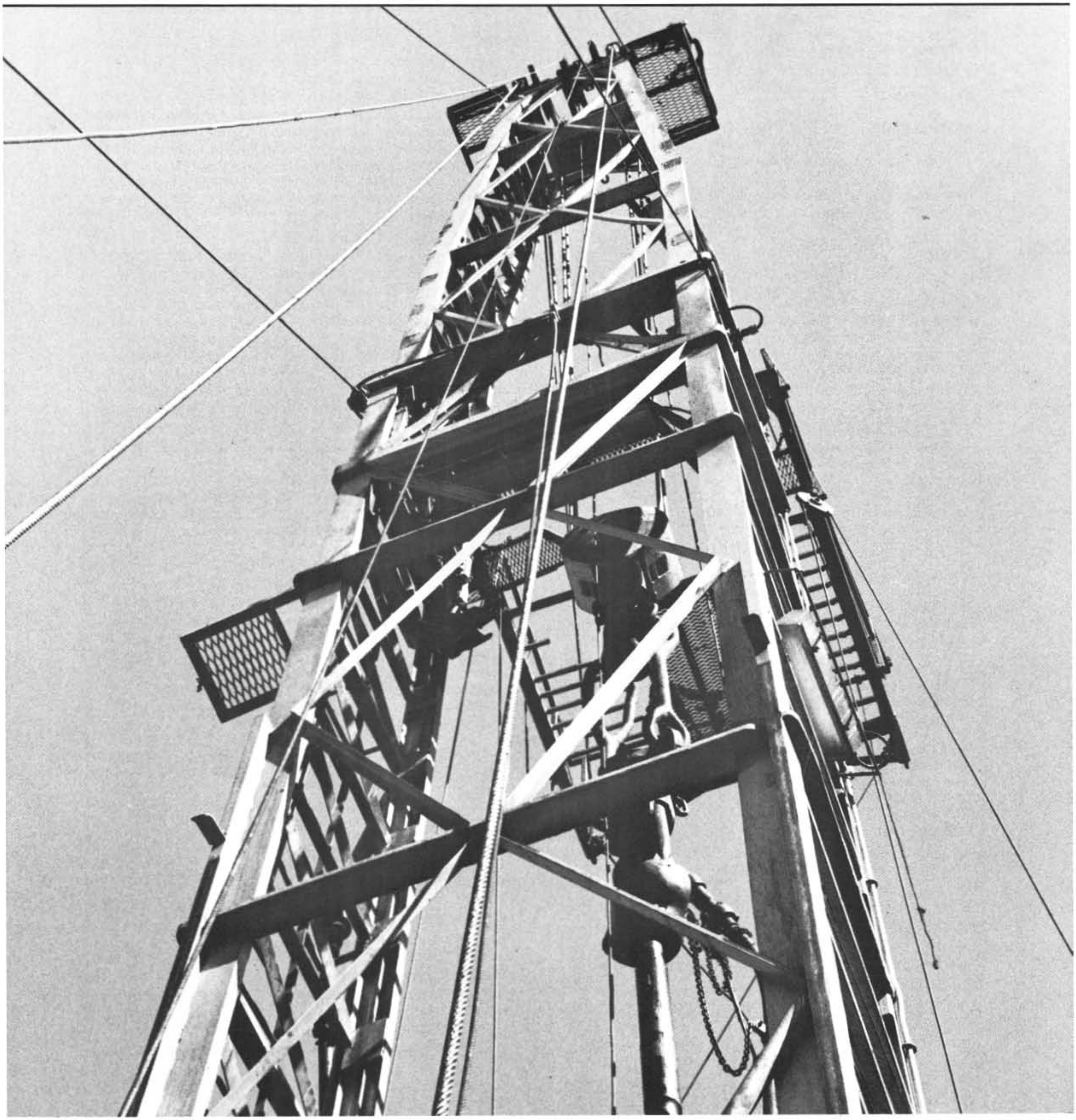

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NEXT MONTH:

Geothermal Exploration in Oregon, 1980, by George R. Priest and Dennis L. Olmstead; and *Surface Mined Land Reclamation in Oregon, 1980*, by Paul F. Lawson.

COVER PHOTO

Derrick owned by Paul Graham Drilling Co. of Rio Vista, Calif., drilling for gas in the Mist Gas Field under contract with Reichhold Energy Corp.

DOGAMI issues lineation study of the northern Cascades of Oregon

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the completion of a photo and imagery study of the northern Cascades, from the Columbia River on the north to the Willamette Pass area on the south.

The study is released as DOGAMI Special Paper 12, entitled *Geologic Linears of the Northern Part of the Cascade Range, Oregon*. It was prepared by R. Venkatakrishnan, J.G. Bond, and J.D. Kauffman of Geoscience Consultants, Moscow, Idaho, and contains five maps of geologic linears (four at a scale of 1:250,000 and one at a scale of 1:1,000,000) and a 25-page interpretive text.

Linears, or lineaments, can help identify previously unmapped faults and folds, which in turn are used to find areas of mineral deposits and geothermal systems, to assess the earthquake potential, and to develop an understanding of the general mountain-building history of the Cascade Range. Basis for the study are high-altitude (U-2) infrared photos, side-looking airborne radar (SLAR) mosaics, and orbital (LANDSAT) multispectral scanner imagery.

Special Paper 12 may be purchased for $3.00 from the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. Payment must accompany orders of less than $20.00. □

Oregon diamond find has been verified

Oregon diamonds are fact, not rumor. Although major diamond production is from Africa, other parts of the world, including the United States, have known diamond occurrences. Oregon is but one of several states where reported diamond finds have been verified.

Diamond "finds" have been reported in Oregon since 1890. Kunz (1890) and Blank (1935) reported diamonds in the placer gold gravels of southwestern Oregon. Kunz (1890) also reported microdiamonds in the platinum placer sands of southwestern Oregon.

One authenticated diamond has been discovered in Oregon. This stone is part of the Smithsonian Natural History Museum mineral collection (specimen number R7826). The diamond, which was found prior to 1938 near Wedderburn, Curry County, Oregon, weighs 0.6 carats and is a clear white, flattened hexoctahedron with minor carbon inclusions. This stone was purchased by the Smithsonian Institution from Mr. A. Montgomery on February 15, 1938, for $25.50.

References cited

Blank, E.W., 1935, Diamond finds in the United States, *in* Rocks and minerals: Jersey City, N.J., Colgate-Palmolive-Peet Co., parts III and V.

Kunz, G., 1890, Gems and precious stones of North America: New York, Scientific Publishing Co., p. 28-29.

—Steven R. Munts, Bureau of Mines, E. 360 Third Avenue, Spokane, Wash. 99202 □

CONTENTS

Oil and gas exploration and development in Oregon, 1980

by Dennis L. Olmstead, Petroleum Engineer, Oregon Department of Geology and Mineral Industries

ABSTRACT

1980 was the busiest year to date for oil and gas exploratory drilling in Oregon. The activity, totaling 31 wells and nine redrills, stemmed from the discovery in 1979 of the Mist Gas Field in Columbia County.

Drilling continued at Mist but also spread to the Willamette Valley and the coastal counties of Clatsop, Coos, Douglas, and Lincoln. The State was also the site of much oil and gas leasing, both along the coast and in central and eastern Oregon.

LEASING ACTIVITY

The 1979 gas discovery near Mist, in Columbia County, inspired increased oil and gas leasing during 1980. The activity spread statewide but was slowed by a Bureau of Land Management (BLM) moratorium on all Federal onshore noncompetitive oil and gas leasing.

BLM noncompetitive leases are issued on land where there are no known producing geological structures. Over-the-counter (OTC) leases are granted on new applications, while simultaneous oil and gas (SOG) or "lottery" leases are granted on property previously leased but then relinquished, expired, terminated, or canceled. Former Interior Secretary Cecil Andrus suspended both OTC and SOG leasing from late February to June 1980 to correct abuses disclosed by a BLM investigation. Upon resumption of application processing in June, the BLM began to computerize the leasing system to enable the agency to monitor it more closely.

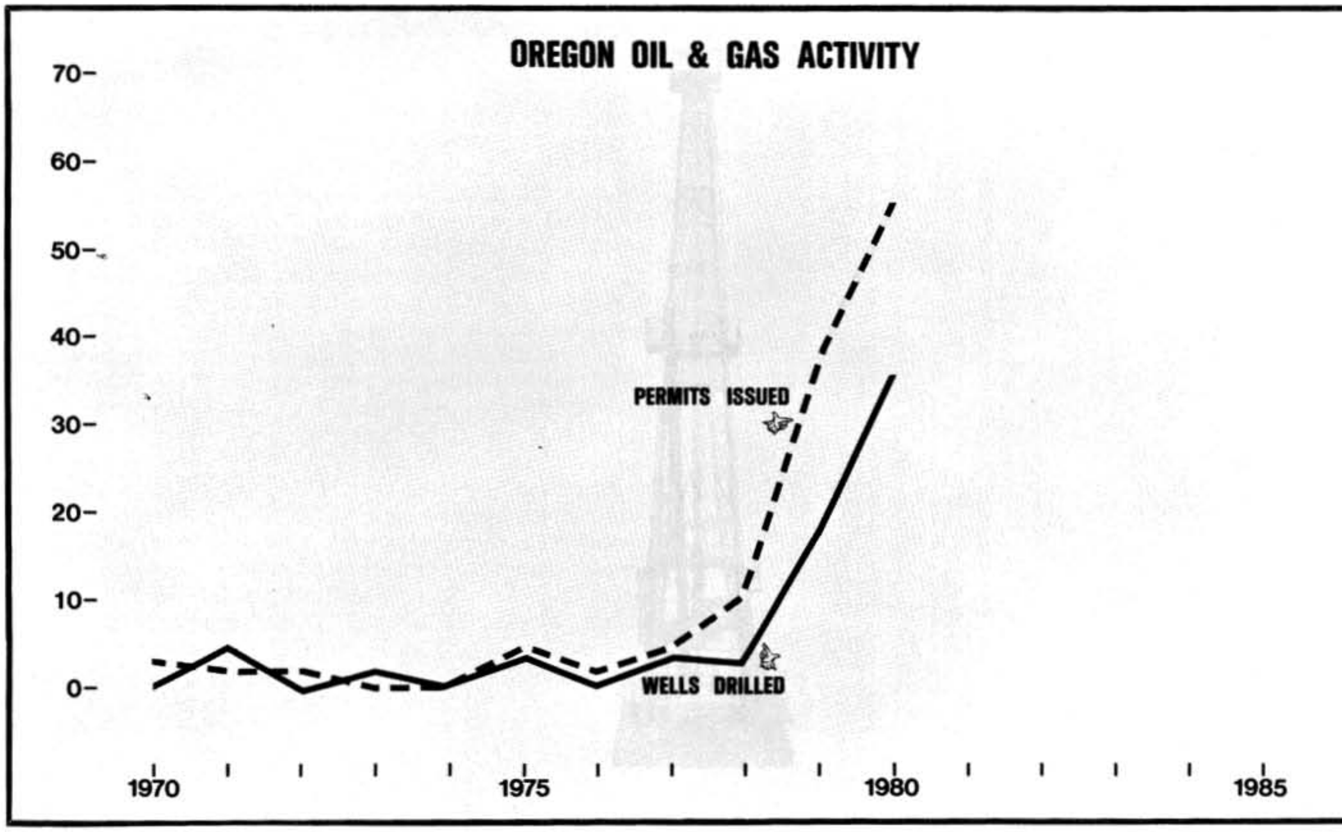
By the end of 1980, statewide Federal leaseholds totaled 723,537 acres, with pending applications for 4,511,924 acres more.

Three lease sales where bidders offered bonus payments to win leases in twelve counties were held by the Oregon Division of State Lands during the year. Bonus bids of up to $287 per acre were offered on parcels of land totaling nearly 70,000 acres. Bonus payments to the State reached a sum of $3.7 million. The western Oregon counties of Clatsop, Columbia, and Douglas were the sites of the most leased acreage; while lands adjacent to the gas production at Mist received the highest bids, interest was much lower for other parts of the State. Rental terms for State leases are one dollar per acre per year and ⅛ royalty in the event of a discovery.

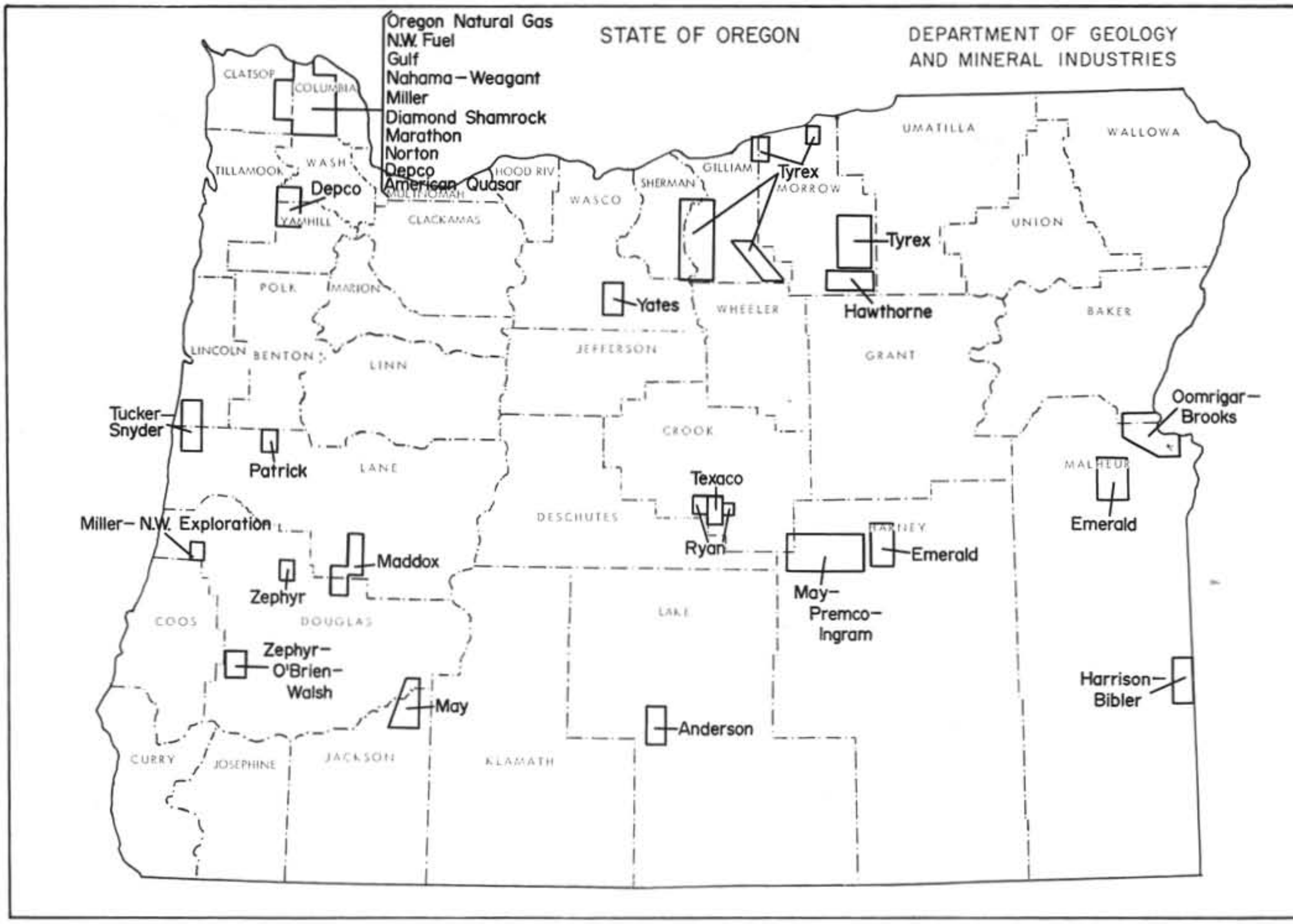
Fee leasing also increased during 1980, but in many cases leases were not recorded with the counties. Eastern Oregon counties, especially those bordering the Columbia River, saw a rapid increase in leasing activity.

DRILLING ACTIVITY

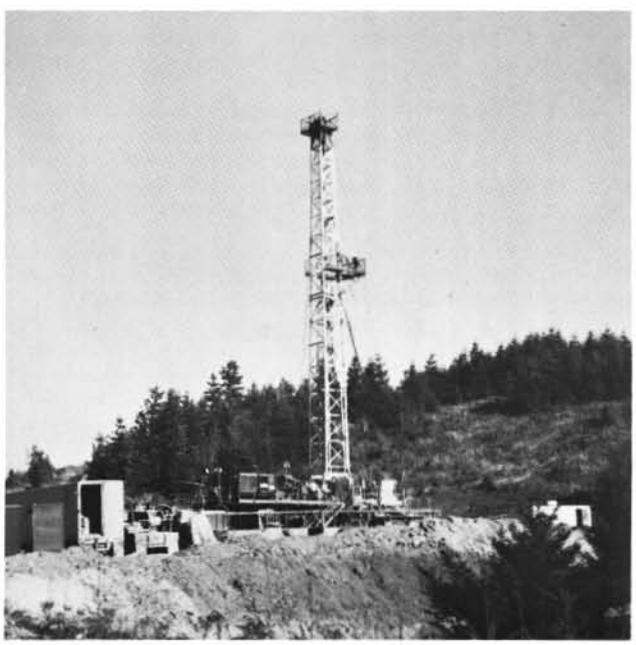
Oregon's new status as a producing state resulted in a dramatic increase in drilling during 1980. From a total of two wells in 1978 and sixteen in 1979, there was an increase to 31 exploratory and development wells drilled during 1980, as well as many redrills. This dramatic increase in just two years is graphic proof that the energy industry now takes Oregon seriously. Still, major companies have been cautious about



Oil and gas activity in Oregon since 1970.



Oil and gas leases obtained in Oregon, 1980.



Northwest Exploration Company drilling Coos County 1, north of Coquille, Oregon, to a depth of 6,821 ft. The well was abandoned as a dry hole.

moving into Oregon, and the drilling activity has been conducted by local companies and independents.

The Mist Gas Field in Columbia County (see *Oregon Geology*, December 1980) was the site of most of the drilling effort for the year, with 18 wells drilled within the field boundaries and four more within a radius of a few miles. The remaining nine wells were drilled in coastal counties and in the Willamette Valley, where only subcommercial amounts of hydrocarbons have been found in the past.

Seven different operators drilled wells in Oregon during 1980; four had drilled no previous holes in the State. Wells were drilled to modest depths again, the deepest hole penetrating to 7,068 ft in Clatsop County. Nevertheless, total footage, including redrills, set a new State record at 128,000 ft, an increase of 36 percent over 1979 footage. The trend toward increased footage and the spread of drilling to diverse points of the State give the industry a better chance of making another discovery in Oregon. 1980 activity, however, resulted in only two new gas wells at Mist, one of them productive enough to be immediately piped to market. No new fields were discovered.

Reichhold Energy Corporation and its partners Diamond Shamrock and Northwest Natural Gas Company continue to be the only producers at Mist, but American Quasar Petroleum Company has also continued intensive drilling in the area. American Quasar also expanded its exploratory effort into the Willamette Valley in 1980 (Table 1), drilling one well and scheduling two more. These companies were joined in the

Table 1. *Oil and gas permits and drilling activity in Oregon, 1980*

Permit no.	Operator	Well name	Location	TD: Total depth (ft) RD: Redrill depth (ft)	Status
73 RD	Reichhold Energy Corp.	Longview Fibre 1	SW¼ sec. 11 T. 6 N., R. 5 W. Columbia County	RD: 2,803	Abandoned; dry hole.
115	Reichhold Energy Corp.	Columbia County 12	NW¼ sec. 14 T. 6 N., R. 5 W. Columbia County	TD: 3,160 RD: 3,365	Suspended.
116	Oregon Natural Gas Development Corp.	Crown Zellerbach 1	NW¼ sec. 13 T. 2 S., R. 10 W. Tillamook County	TD: 6,158	Abandoned; dry hole.
117	John T. Miller	John Stump 1	NW¼ sec. 26 T. 8 S., R. 5 W. Polk County	TD: 1,502	Suspended; dry hole.
119	American Quasar Petroleum Co.	Wall 24-21	SW¼ sec. 24 T. 6 N., R. 5 W. Columbia County	TD: 2,810	Abandoned; dry hole.
121	American Quasar Petroleum Co.	Longview Fibre 25-32	NE¼ sec. 25 T. 6 N., R. 5 W. Columbia County	TD: 2,902 RD: 3,261	Abandoned; dry hole.
122	American Quasar Petroleum Co.	Crown Zellerbach 14-21	NW¼ sec. 14 T. 5 N., R. 5 W. Columbia County	TD: 1,832	Abandoned; dry hole.
123	Reichhold Energy Corp.	Columbia County 11-10	NW¼ sec. 10 T. 6 N., R. 5 W. Columbia County	–	Permit issued.
124	Reichhold Energy Corp.	Columbia County 33-3	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	TD: 2,777	Completed, gas; Mist Gas Field.
125	Reichhold Energy Corp.	Columbia County 43-11	SE¼ sec. 11 T. 6 N., R. 5 W. Columbia County	TD: 3,326 RD: 3,626	Abandoned; dry hole.
126	Reichhold Energy Corp.	Crown Zellerbach 42-1	NE¼ sec. 1 T. 6 N., R. 5 W. Columbia County	TD: 2,892	Completed, gas; Mist Gas Field.
127	Reichhold Energy Corp.	Longview Fibre 34-12	SE¼ sec. 12 T. 6 N., R. 5 W. Columbia County	–	Permit issued.
128	Reichhold Energy Corp.	Libel 44-15	SE¼ sec. 15 T. 6 N., R. 5 W. Columbia County	–	Permit issued.
129	Reichhold Energy Corp.	Columbia County 44-4	SE¼ sec. 4 T. 6 N., R. 5 W. Columbia County	TD: 3,061	Abandoned; dry hole.
130	Reichhold Energy Corp.	Columbia County 21-10	NW¼ sec. 10 T. 6 N., R. 5 W. Columbia County	–	Permit issued.
131	Reichhold Energy Corp.	Columbia County 32-3	NE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	TD: 3,395	Suspended.
132	Reichhold Energy Corp.	Laubach 34-13	SE¼ sec. 13 T. 6 N., R. 5 W. Columbia County	–	Permit issued.
133	Reichhold Energy Corp.	Libel 22-15	NW¼ sec. 15 T. 6 N., R. 5 W. Columbia County	–	Permit issued.
134	Reichhold Energy Corp.	Longview Fibre 33-12	SE¼ sec. 12 T. 6 N., R. 5 W. Columbia County	–	Permit issued.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1980—Continued*

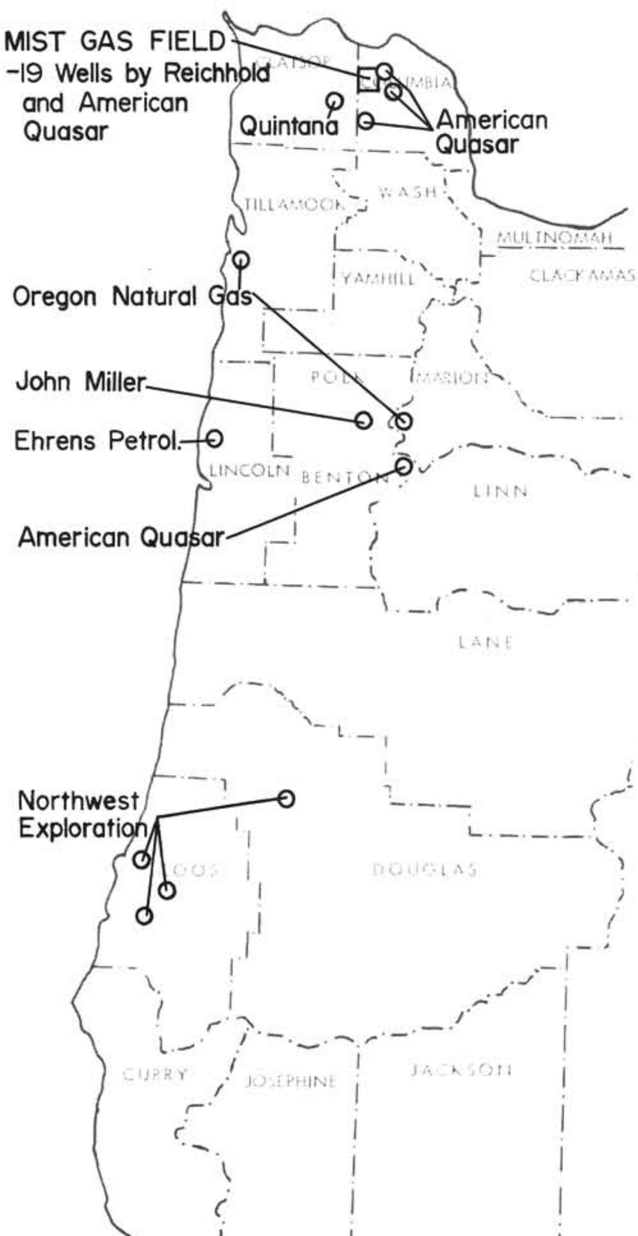
Permit no.	Operator	Well name	Location	TD: Total depth (ft) RD: Redrill depth (ft)	Status
135	Reichhold Energy Corp.	White 33-13	SE¼ sec. 13 T. 6 N., R. 5 W. Columbia County	TD: 2,708	Abandoned; dry hole.
136	Northwest Exploration Co.	Coos County 1	NE¼ sec. 14 T. 27 S., R. 13 W. Coos County	TD: 6,821	Abandoned; dry hole.
137	Northwest Exploration Co.	Westport 1	NW¼ sec. 16 T. 26 S., R. 13 W. Coos County	TD: 3,700	Abandoned; dry hole.
138	Northwest Exploration Co.	Fat Elk 1	SW¼ sec. 15 T. 28 S., R. 13 W. Coos County	TD: 3,110	Abandoned; dry hole.
139	Northwest Exploration Co.	Sawyer Rapids 1	NE¼ sec. 3 T. 23 S., R. 9 W. Douglas County	TD: 5,563	Abandoned; dry hole.
140	Reichhold Energy Corp.	Longview Fibre 24-12	SW¼ sec. 12 T. 6 N., R. 5 W. Columbia County	TD: 2,839	Suspended.
141	Northwest Exploration Co.	Fish Trap 1	NE¼ sec. 32 T. 28 S., R. 13 W. Coos County	—	Permit issued.
142	Reichhold Energy Corp.	Adams 32-34	NE¼ sec. 34 T. 7 N., R. 5 W. Columbia County	—	Permit issued.
143	Reichhold Energy Corp.	Adams 24-34	SW¼ sec. 34 T. 7 N., R. 5 W. Columbia County	TD: 3,377	Abandoned; dry hole.
144	Reichhold Energy Corp.	Adams 23-34	SW¼ sec. 34 T. 7 N., R. 5 W. Columbia County	—	Permit issued.
145	Reichhold Energy Corp.	Columbia County 21-34	NW¼ sec. 34 T. 7 N., R. 5 W. Columbia County	—	Permit issued.
146	Reichhold Energy Corp.	Columbia County 11-33	NW¼ sec. 33 T. 7 N., R. 5 W. Columbia County	—	Permit issued.
147	Reichhold Energy Corp.	Columbia County 12-9	NW¼ sec. 9 T. 6 N., R. 5 W. Columbia County	TD: 2,918	Suspended.
148	Reichhold Energy Corp.	Columbia County 32-5	NE¼ sec. 5 T. 6 N., R. 5 W. Columbia County	—	Permit issued.
149	Reichhold Energy Corp.	Columbia County 31-3	NE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	—	Permit issued.
150	Reichhold Energy Corp.	Columbia County 42-4	NE¼ sec. 4 T. 6 N., R. 5 W. Columbia County	—	Permit issued.
151	Reichhold Energy Corp.	Columbia County 22-3	NW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	—	Permit issued.
152	Reichhold Energy Corp.	Longview Fibre 23-12	SW¼ sec. 12 T. 6 N., R. 5 W. Columbia County	—	Permit issued.
153	Reichhold Energy Corp.	Columbia County 13-2	SW¼ sec. 2 T. 6 N., R. 5 W. Columbia County	TD: 3,709 RD: 3,823	Suspended.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1980—Continued*

Permit no.	Operator	Well name	Location	TD: Total depth (ft) RD: Redrill depth (ft)	Status
154	American Quasar Petroleum Co.	Investment Management 34-21	NW¼ sec. 34 T. 6 N., R. 4 W. Columbia County	TD: 4,080	Abandoned; dry hole.
155	American Quasar Petroleum Co.	Larkins 23-33	SE¼ sec. 23 T. 6 N., R. 5 W. Columbia County	TD: 2,940	Abandoned; dry hole.
156	American Quasar Petroleum Co.	Rau 18-14	SW¼ sec. 18 T. 6 N., R. 4 W. Columbia County	TD: 2,434 RD: 2,440	Abandoned; dry hole.
157	American Quasar Petroleum Co.	Crown Zellerbach 30-33	SE¼ sec. 30 T. 6 N., R. 4 W. Columbia County	TD: 2,350	Abandoned; dry hole.
158	Reichhold Energy Corp.	Columbia County 14-2	SW¼ sec. 2 T. 6 N., R. 5 W. Columbia County	TD: 3,582	Suspended.
159	Reichhold Energy Corp.	Sweet 14-1	SW¼ sec. 1 T. 6 N., R. 5 W. Columbia County	–	Permit issued.
160	Oregon Natural Gas Development Corp.	Independence 12-25	NW¼ sec. 25 T. 8 S., R. 4 W. Marion County	TD: 4,826	Abandoned; dry hole.
161	Reichhold Energy Corp.	Baganoff 23-28	SW¼ sec. 28 T. 5 S., R. 2 W. Marion County	–	Permit issued.
162	Reichhold Energy Corp.	Crown Zellerbach 22-6	NW¼ sec. 6 T. 6 N., R. 4 W. Columbia County	TD: 3,671 RD 1: 2,264 RD 2: 2,431	Abandoned; dry hole.
163	Northwest Exploration Co.	Fat Elk 2	NE¼ sec. 11 T. 28 S., R. 13 W. Coos County	–	Permit issued.
164	American Quasar Petroleum Co.	Investment Management 20-21	NW¼ sec. 20 T. 6 N., R. 4 W. Columbia County	TD: 2,281 RD: 2,145	Abandoned; dry hole.
165	American Quasar Petroleum Co.	Wilna Inc. et al. 6-43	SE¼ sec. 6 T. 6 N., R. 4 W. Columbia County	–	Permit issued.
166	Texaco Inc.	USL-OR 17-1	NE¼ sec. 17 T. 19 S., R. 20 E. Crook County	–	Drilling.
167	Ehrens Petroleum & Development, Inc.	Longview Fibre 1	NE¼ sec. 20 T. 9 S., R. 11 W. Lincoln County	–	Drilling.
168	Ehrens Petroleum & Development, Inc.	Longview Fibre 2	NW¼ sec. 28 T. 9 S., R. 11 W. Lincoln County	TD: 2,004	Idle.
169	Reichhold Energy Corp.	Columbia County 14-34	SW¼ sec. 34 T. 7 N., R. 5 W. Columbia County	–	Permit issued.
170	Quintana Petroleum Corp.	Watzek et al. 30-1	NW¼ sec. 30 T. 6 N., R. 6 W. Clatsop County	TD: 7,068	Abandoned; dry hole.
171	John T. Miller	Bork 1	SE¼ sec. 26 T. 8 S., R. 5 W. Polk County	TD: 1,030	Idle.
172	American Quasar Petroleum Co.	Hickey 9-12	NW¼ sec. 9 T. 12 S., R. 2 W. Linn County	–	Drilling.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1980—Continued*

Permit no.	Operator	Well name	Location	TD: Total depth (ft) RD: Redrill depth (ft)	Status
173	American Quasar Petroleum Co.	Henschel 17-34	SE¼ sec. 17 T. 10 S., R. 3 W. Linn County	TD: 2,856	Abandoned; dry hole.
174	American Quasar Petroleum Co.	M & P Farms 33-24	SW¼ sec. 33 T. 11 S., R. 4 W. Linn County	—	Permit issued.
175	American Quasar Petroleum Co.	Wilna et al. 5-23	SW¼ sec. 5 T. 6 N., R. 4 W. Columbia County	TD: 4,503	Abandoned; dry hole.



Oil and gas drilling sites in Oregon, 1980. All drilling was in western Oregon.

During 1980, Northwest Natural Gas Company installed a gathering line for Columbia County 10 in the Mist Gas Field.

area by Oregon Natural Gas Development Company and John T. Miller, who also carried out exploratory drilling.

GAS PRODUCTION

Initial gas production from the Mist Gas Field occurred during the final days of 1979, with one well on line. Subsequent installation of a gathering line brought the number of wells on line to five and the total daily production of the field to 21 million cubic feet per day. Two additional wells are capable of production but do not have gathering lines. Of the seven capable wells, two were drilled and completed in 1980, with a capacity of 7 million cubic feet of gas per day. This decrease in the number of completed wells is the only statistic that dropped at the Mist Field.

The value of the gas produced at Mist is based on its heating value and is set by Federal price guidelines. Mist gas provides about 9.2 "therms" per thousand cubic feet (Mcf), and the price rose during the year from $0.2358 per therm in

(Continued, p. 38)

Mineral industry in Oregon, 1980

by Jerry J. Gray, Economic Geologist, Albany Field Office; Howard C. Brooks, Resident Geologist, Baker Field Office; Norman V. Peterson, District Geologist, and Len Ramp, Resident Geologist, Grants Pass Field Office, Oregon Department of Geology and Mineral Industries

MINERAL PRODUCTION STATISTICS

Oregon's mineral production values for 1979 and 1980 are summarized in Table 1. This table does not include an additional estimated $600 million from the production of aluminum, carbide, nickel, steel, titanium, and zirconium at metallurgical plants employing approximately 11,000 people.

During 1978, a Federal reorganization caused the U.S. Bureau of Mines to stop canvassing for mineral production statistics for crude petroleum, petroleum, natural gas liquids, natural gas, anthracite and bituminous coal, lignite, and uranium. This change did not affect Oregon until 1980 because none of these minerals were being produced in the State. However, a major change occurred in Oregon mineral output during the last month of 1979: natural gas from the Mist Gas Field started flowing to market. At $2.34 per thousand cubic feet, $3,000 of natural gas was produced during 1979. During 1980, the first full production year, $11.6 million was produced. The value of mineral production value in Table 1 will not be comparable to that formally published by the Bureau of Mines because of the extra value from natural gas.

The Bureau's preliminary figures for 1980 indicate that the national high interest rate with its corresponding drop in construction has caught up with Oregon's historical mineral-production mainstay, rock materials (clay, pumice, sand and gravel, and stone), causing a 14-percent drop in value of output. During 1979, rock material accounted for 68 percent of the total; however, with natural gas output, in 1980 rock material production dropped to 57 percent of total production. The year 1980 also saw a new mineral, zeolite, added to the production list.

Table 1. *Oregon's mineral production values for 1979 and 1980*

	1979		1980	
Mineral commodity	Value ($1,000)	Percent	Value* ($1,000)	Percent*
Stone	65,074	39	56,300	33
Cement, copper, diatomite, gold, nickel, silver, talc, zeolite	51,891	31	61,760	36
Sand and gravel	45,829	28	39,000	23
Natural gas	3	–	11,552	7
Pumice	1,644	1	2,005	1
Gemstones	500	0.3	486	0.3
Clays	263	0.2	251	0.2
TOTAL	165,210	99.5**	171,354	100.5**

* Preliminary data provided by U.S. Bureau of Mines.
** Percentages do not total 100 because of individual rounding.

METALS

Placering

With the price of gold in the range of $500-$650 per ounce, great numbers of men, women, and children have taken up gold placering for fun and profit. Others are selling small-scale placering equipment for profit. If statistics could be obtained, they might show that the value of placering equipment sold is far greater than the value of gold found with that equipment.

The largest output of placer gold was produced at the U.S. Army Corps of Engineers construction site for the rock-filled Applegate River Dam (Point 29*). All of the gravel that was used in the fill and as aggregate for the concrete was screened, and the minus-⅜th-mesh material was run through a gold-recovery system. Total gold recovered was about $2.5 million, with the Corps' share being $0.8 million. The gravel averaged about $1 per yard in recovered gold. Other gold placer operations which operated all field season were Mormon Basin Mines Company (Point 17) and Delta Investors (Point 18), both on Basin Creek in Malheur County; Gallagher's on Sucker Creek (Point 32); and Bentley's on Fry Gulch near the old town site of Waldo (Point 33). The Eagle and the Pioneer chrome/gold beach-sand mines (Point 23) near Bandon are being operated by W-S Mining. The firm is processing about 250 cu yd per day through screens and sluice boxes to recover the gold and platinum metals. The chromite-rich black-sand concentrates are being saved.

* All point numbers refer to locations shown on the location map.

Lode mining

Output of contained nickel in ferronickel from Hanna Mining Company's mine at Nickel Mountain (the nation's only domestic mine source of nickel) and their smelter complex at Riddle (Point 24) rose from 15,065 tons in 1979 to 16,117 tons in 1980.

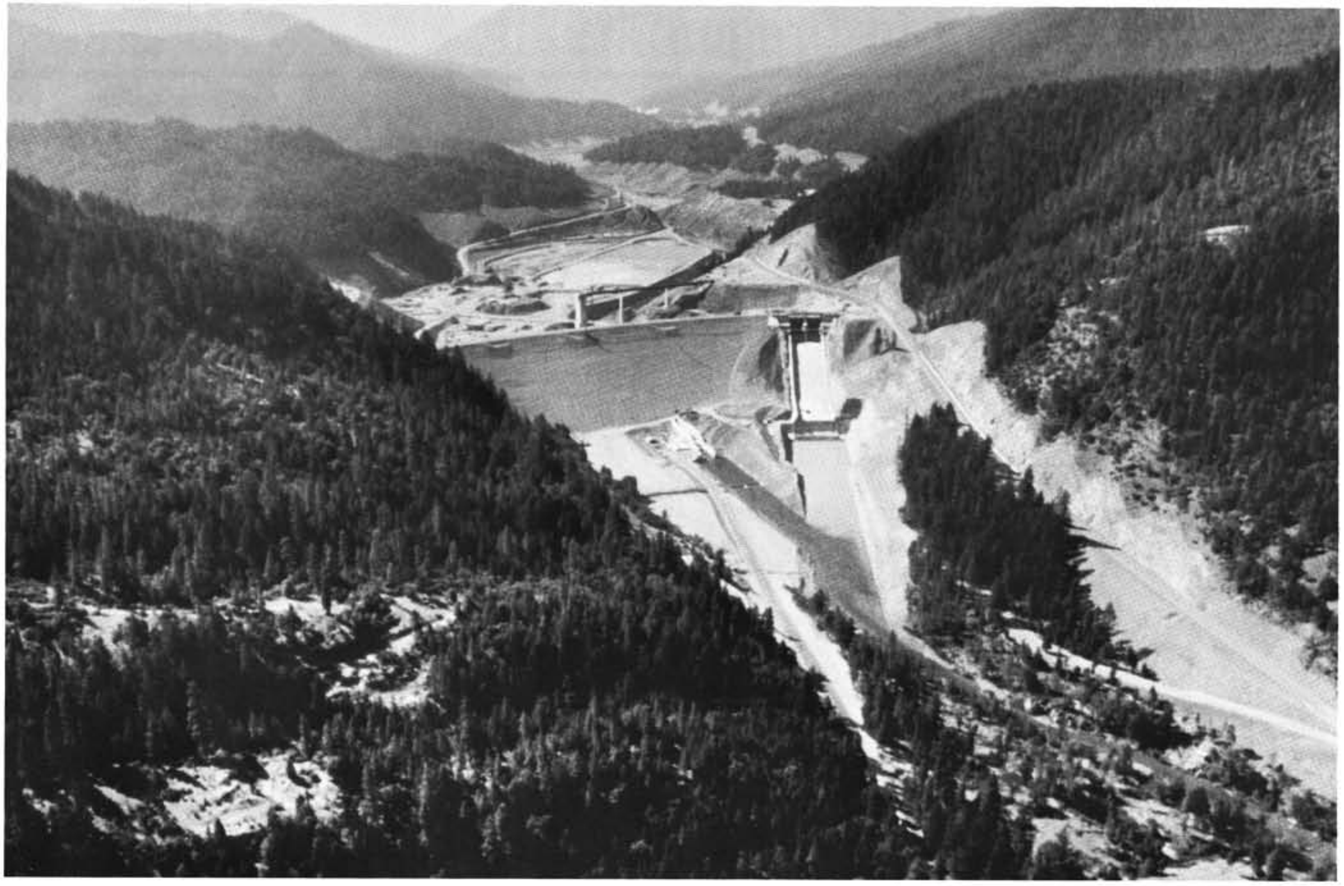
About 150 tons of ore per day from the Iron Dyke mines (Point 11) is trucked by Silver King Mining 22.5 mi to the firm's 800-tons-per-day flotation mill near Cuprum, Idaho, for concentration. Employment at the mine averaged 35.

The Buffalo Mining Company's flotation mill (Point 12) was operated part of the year at the rate of 2 tons of ore per hour, 16 hours per day, from ore obtained from the 600- and 500-adit levels of the Buffalo Mine. Rehabilitation work continues on these levels.

Metal processing

Because the Bonneville Power Administration (BPA) curtailed the delivery of interruptible electric power, Reynolds Metals Company closed down one of its five pot lines from March to July, at its Troutdale aluminum plant (Point 3). The line was restarted with power purchased outside of BPA grids. By year's end, all pot lines were back to full production. Total production loss for the year amounted to about 16 percent.

A Danish firm, Bergsoe Metal Corporation, is building a $25-million lead-recycling plant at St. Helens (Point 1). Construction began in March 1980 and is to be completed by fall of 1981. The plant will have the capacity to reclaim 50,000 tons of



Aerial view of the recently constructed Applegate Dam. Gold valued at $2.5 million was recovered from gravel excavated from area now covered by dam and pond and used for dam fill and concrete.

Ground level view of Mormon Basin Placer, Inc., gold placer operation on Basin Creek, showing draglines and gold recovery plant.

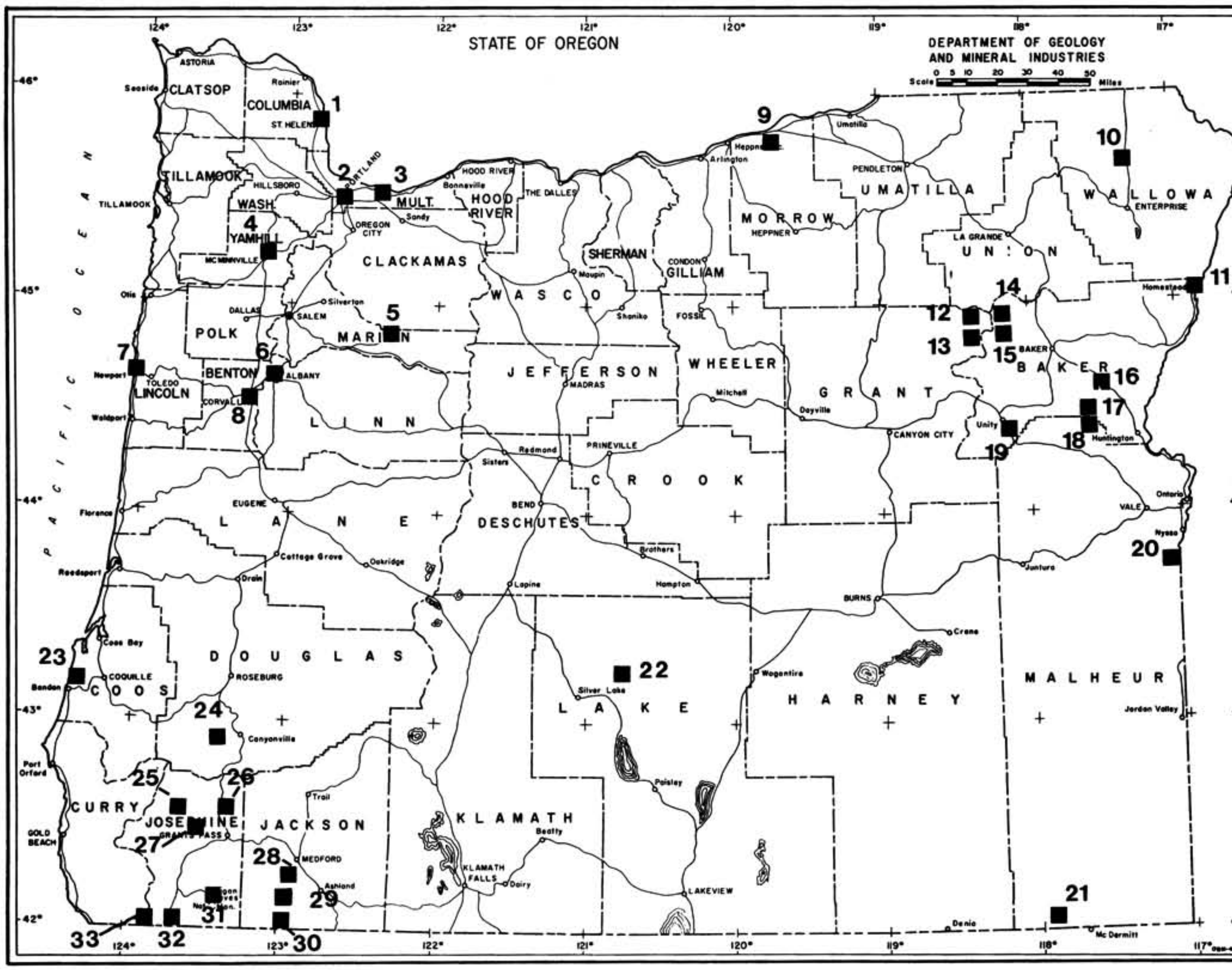
lead (equivalent to 2.5 million car batteries) annually from storage batteries.

Oregon Metallurgical Corporation, Albany (Point 6), started the construction of a new titanium sponge facility which will increase the company's sponge capacity by 50 percent from 3,000 tons to 4,500 tons. The plant is expected to be completed by mid-1981 and to cost $7-10 million. Also under construction is a titanium mill-products plant which will allow the company to take its large ingots and forge them down to smaller billets which can be handled by more firms. Teledyne Wah Chang of Albany (Point 6), a producer of zirconium, continued to curtail employment because of low demand for the metal. Cascade Steel Rolling Mills, McMinnville (Point 4), announced a $6-million expansion of its mill facilities, to be completed in early 1981. The firm uses scrap to produce electric-furnace steel which is rolled into reinforcing bags and steel fence posts.

NONMETALS

Oregon Portland Cement Company completed its first-year run of its new cement plant near Durkee (Point 16). Capacity of the new plant is about 500,000 tons of cement per year, which is twice the size of the replaced plant at Lime, a few miles to the south. Limestone for the new plant is quarried at the same site.

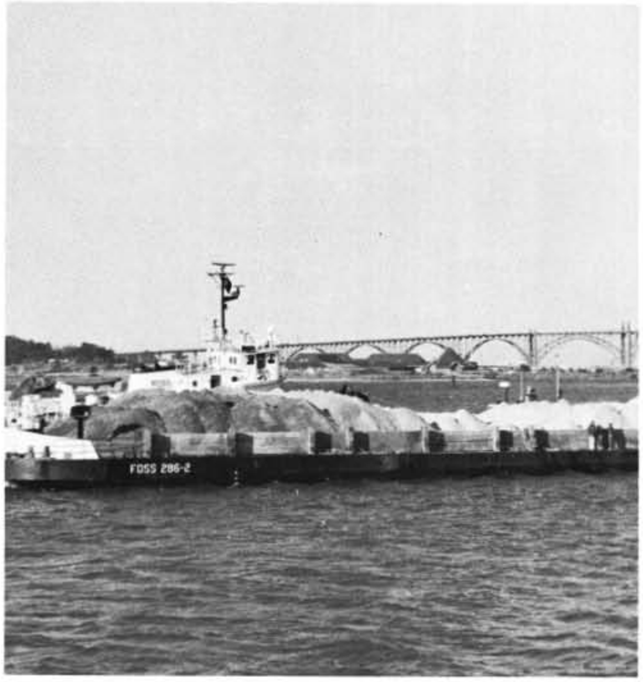
Limestone marketing in the Willamette Valley has been changed by the importation by barge of limestone from Texada Island, B.C., to Newport (Point 7). Prior to this time, Morse Brothers, Inc., supplied limestone to the valley by barge



EXPLANATION

1. St. Helens (Pb)
2. Portland (sand and gravel)
3. Troutdale-Gresham (Al, brick)
4. McMinnville (steel)
5. Santiam mining district (Cu)
6. Albany (Ti-Zr)
7. Newport (limestone, stone)
8. Corvallis (limestone, sand and gravel)
9. Boardman (fly ash)
10. Flora (coal)
11. Iron Dyke Mine (Cu, Au)
12. Buffalo Mine (Au, Ag)
13. Cougar-New York Mine (Au, Ag)
14. Meadow Lake (Cu-Mo)
15. Bourne (Au)
16. Durkee (cement)
17. Mormon Basin Mine (Au)
18. Basin Creek Mine (Au)
19. Unity (Cu)
20. Adrian (bentonite, zeolite)
21. McDermitt (U)
22. Christmas Valley (diatomite)
23. Eagle, Pioneer Mines (Au, Cr)
24. Nickel Mountain (Ni)
25. Black Bear Mine (Au)
26. Greenback Mine (Au)
27. Last Flat Mine (Au)
28. Sugarloaf Hill (Au)
29. Applegate Dam (Au)
30. Steatite of Oregon (soapstone)
31. Boswell, Rainbow Mines (Au)
32. Sucker Creek, Queen of Bronze Mine (Cu, Au)
33. Turner-Albright Mine, Fry Gulch (Cu, Co, Au)

Mineral industry activity, exploration, and development in Oregon in 1980. Point numbers in text refer to location numbers shown on this map.



A barge load of Texada Island, B.C., limestone docking at Newport, Oregon. A 6,000-ton barge load of 3-in. minus limestone is being pushed to a dock at Newport. The barge will be unloaded in 8 hours and moved to a nearby stockpile by Morse Brothers, Inc., equipment waiting dockside.

from Texada Island to Portland, then south by rail. However, transportation cost increases kept driving up the price of the delivered stone. Meanwhile, because the Pacific Coast area at Newport lacks concrete-grade aggregate, Morse Brothers was supplying it by truck from Corvallis (Point 8), a distance of 55 mi. Because the trucks did not have a load to haul back, they were driven back empty. Now the limestone provides a back haul, which divides the cost of the trucking between two commodities, aggregate to Newport, limestone to Corvallis. The 6,000-ton barge load of minus-3-in. limestone is unloaded and trucked to a nearby stockpile in 8 hours. It is then trucked to the Corvallis plant, where it is crushed and screened for use in paper manufacture and agriculture.

Construction was started on a $6-million brick-manufacturing plant for Columbia Brick Works at Gresham (Point 3). The new plant is to have an annual capacity of 48 million bricks. The old plant employed about 25 persons and produced about 17 million bricks per year.

Oil-Dri West continues to mine and process diatomaceous earth for pet litter and floor-sweep absorbent from its Christmas Valley site (Point 22). Diatomaceous earth is composed of clay and diatoms (skeletons of microscopic aquatic plants).

Steatite of Oregon continues to mine and market block soapstone from its Jackson County deposit (Point 30) for art carving and other specialty uses.

Teague Mineral Products still produces bentonite from its Malheur County site. The clay, mined from pits near the head of Sucker Creek, is used for a binder in sandcasting molds and for hay cubes, pond sealants, and fire retardants. The firm bought a Raymond grinding mill from the Midwest and had it shipped to its Adrian drying-bagging plant (Point 20). After the mill was reassembled, it was used to fine-grind zeolite from a deposit 30 mi south of the bentonite pits. The zeolite was used as a hog-feed supplement.

When the Boardman coal-fired power plant (Point 9) comes on line in July, it will produce large amounts of fly ash. Fly ash can be used for pozzolan. Up to one-third of the cement in concrete can be replaced with pozzolan. The pozzolan

Morse Brothers, Inc., limestone crushing-screening plant at Corvallis, the crushing-screening plant for Texada Island, B.C., limestone imported to Newport. The limestone is used as back haul for trucks bringing gravel from Corvallis to Morse Brothers, Inc., ready-mix plant in Newport.

Aerial view of Yaquina Head, major source of rock material for Newport area. Federal law requires that the Bureau of Land Management purchase this landmark from Yaquina Head Quarries, Inc., by 1982.

produces a stronger and more durable, watertight, easily placed, and worked concrete. Coal for the plant is mined from the Gillette, Wyoming, area. It is transported from the mine to the plant by a 100-car unit train. The round trip is 2,400 mi; 10,000 tons are carried each trip which takes 2½ days.

The Portland City Council approved a conditional use permit for Ross Island Sand and Gravel Company (Point 2), which allows the firm to continue to mine at about the same rate as in the past (1 million cu yd per year). Mining at the site could go on for another 35 years, and part of the island would be rebuilt from dredging spoils. At this time, plans to deed the island after mining and reclamation to the city as an open-space park are under consideration.

A Federal law was passed which requires the Bureau of Land Management to purchase the Yaquina Head Quarries, Inc., quarry site on Yaquina Head near Newport (Point 7) by 1982. The quarry is the main source of stone for the Newport area. Other sources will require much higher transportation costs to serve the Newport market.

EXPLORATION AND DEVELOPMENT

For the northwest portion of the State, specifically the Santiam mining district (Point 5), the leasing of Shiny Rock Mining Company mineral rights by AMOCO is significant. The Santiam district contains zoned mineralization with copper in the center. The two firms each had controlled about one-half of the center zone. After several years of diamond drilling on its side of the center zone, AMOCO started exploring the Shiny Rock side through geological, geochemical, and geophysical studies.

On the northeast side of the State, a joint venture of Brooks Minerals, Inc., and AMAX Exploration, Inc., began reopening old workings of the North Pole and E and E gold mines near Bourne (Point 15). Work involved rehabilitation of part of the North Pole No. 2 and the E and E 400-adit levels, plus surface mapping, sampling, and diamond drilling. The two mines are on the northern part of the North Pole-Columbia lode, which produced more than $8 million between 1894 and 1916. The geology of the Bourne quadrangle and part of the Mount Ireland quadrangle was mapped during the 1980 field season by Oregon Department of Geology and Mineral Industries (DOGAMI) geologists H.C. Brooks and M.L. Ferns. The Bourne map will be placed on open file in early 1981. Maps of the Mount Ireland quadrangle and the adjacent Granite quadrangle are scheduled for completion in 1981. W.A. Bowes and Associates continued exploration and

(Continued, p. 38)

Abstracts of Department geothermal papers given at OAS

These abstracts of papers given at the Oregon Academy of Science, February 28, 1981, at Portland State University in Portland summarize some of the findings of the Oregon Department of Geology and Mineral Industries' current research on low-temperature geothermal assessment and geothermal potential assessment of the Western and High Cascades.

GEOLOGY OF THE COUGAR RESERVOIR AREA, LANE COUNTY, OREGON, *by George R. Priest and Neil Woller, Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, Oregon 97201.*

The study area is located along Cougar Reservoir about 67 km (40 mi) east of Eugene. Volcanic rocks of the Western Cascades predominate, but basaltic lavas from upper Miocene to Pliocene High Cascade vents to the east cap ridges. The following informal volcanic units were used: Tuffs of Cougar Reservoir (laharic and epiclastic tuffs, Oligocene?); Basalts of East Fork (olivine tholeiite altered, early Miocene?); Strube ash-flow tuffs and andesites (early Miocene); Lavas of Cougar Dam (two-pyroxene andesite or basaltic andesite + mafic dikes and diatremes, 16.3 ± 1.8 m.y.); Tuffs of Rush Creek (dacite ash-flow tuffs, 13.9 ± 0.8 m.y.); Andesites of Walker Creek (two-pyroxene andesite, top flow at Katsuk Butte is 11.5 ± 0.5 m.y., top flow at Lookout Ridge is 8.93 ± 0.34 m.y.); Dacite of Castle Rock (hypersthene dacite plug dome, 9.31 ± 0.44 m.y.); Lavas of Tipsoo Butte (diktytaxitic basalt and basaltic andesite, 8.39 to 3.88 m.y.). Important observations include: 1. A major N-S-trending fault zone here called the Cougar Fault follows the east side of Cougar Reservoir; minimum offset is 152 m down to the east; 2. The Cougar Fault controls intrusion of the dike-like mass of lavas of Cougar Dam; 3. The youngest unit offset by the Cougar Fault is 11.5 m.y. but younger movements may have occurred; 4. Between 8.39 ± 0.36 m.y. and 8.93 ± 0.34 m.y., volcanism switched from silicic lavas from Western Cascade vents (Andesites of Walker Creek) to mafic lavas from the High Cascades (Lavas of Tipsoo Butte).

PRELIMINARY GEOLOGY AND GEOTHERMAL RESOURCE EVALUATION OF THE POWELL BUTTES AREA, OREGON, *by David E. Brown, Gary D. McLean, Gerald L. Black and John R. Petros, Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, Oregon 97201.*

During the past two years, the State of Oregon Department of Geology and Mineral Industries has been carrying out a preliminary geothermal resource evaluation of Powell Buttes, a John Day Formation (25-35 m.y.) vent in Crook County, Oregon, under DOE Grant No. DE-FC07-79ET27220. Preliminary logging of existing water wells revealed geothermal gradients 70 to 164°C km^{-1}, centered on an ovoid anomaly along the northwest to western margins of the buttes, which prompted subsequent drilling of eight 500-ft temperature-gradient holes and one 2,000-ft gradient hole. Initial evaluation of available data indicates the buttes are a complexly faulted horst of locally highly altered John Day material surrounded by slightly altered Deschutes Formation basalts, ash flows, and sediments. Boundary faults probably control the geothermal system. Detailed geophysics and deep drilling are necessary to confirm the above geothermal model. □

Oil and gas briefs:

1980: Approximately 3,200 drilling rigs explored for oil and gas in the United States.
1981: Approximately 3,800 drilling rigs are predicted.

1980: Domestic production of oil was 8.6 million Bbl/day, with consumption about 16 million Bbl/day.
1981: Domestic production will be about 8 million Bbl/day.
Mid-1980's: Domestic production will probably reverse the decline and increase to 9 or 10 million Bbl/day.

1980: 62,704 wells were drilled for oil and gas domestically. Previous record for a year was 57,111 (1956). This increase is due to higher prices and profits. OPEC price increases are also spurring domestic search for cheaper crude.
1981: Predictions are that 66,000 wells, an all-time high, will be drilled.

—Oil Daily

(Oil and gas, *continued from p. 32***)**

January to $0.2640 in December. Gas production for the year is valued at about $11.5 million, which is 7 percent of the statewide mineral production for 1980. This is the first time natural gas has been a significant factor in these mineral production statistics. Production leveled off during the last half of the year, and future production trends will depend on the number of new completions.

Reservoir pressures at Mist have declined since the beginning of gas withdrawal, but the life of the field cannot yet be estimated with accuracy. Northwest Natural Gas Company is proceeding with plans to use the field as a gas storage site when the gas reserves are depleted. □

(Mineral industry, *continued from p. 37***)**

development work for gold and silver at the Cougar Mine in the Granite district of Grant County (Point 13).

Preussag, Canada, Ltd., terminated its exploration efforts on the Johns-Manville copper-molybdenum prospect in the Camp Creek-Bull Run Creek area south of Unity (Point 19). Johns-Manville continued some shallow diamond drilling during the summer field season. The firm also shallow-drilled and hand-trenched its Meadow Lake copper prospect (Point 14) near the head of the North Powder River.

Utah International, Inc., Salt Lake City, Utah, requested a conditional use permit from the Wallowa County Planning Commission to excavate a bulk sample of coal from a bed reported to underlie the Flora area (Point 10). The sample is to be used for large-scale testing.

Uranium exploration in southeastern Oregon's Malheur County continued at a high level. In 1978, Placer Amex, Inc., announced the discovery of an ore body located in the McDermitt Caldera (Point 21) tuffaceous lake sediments of late Miocene age and estimated to contain 13 million tons of 0.05 to 0.06 percent U_3O_8.

In southwestern Oregon, work by Baretta Mining, Ltd., on the massive sulfide Turner-Albright copper-cobalt mine (Point 33) included mapping, claim staking, and operating three core drills. Dennison Mining of Toronto, Canada, has optioned the Queen of Bronze Mine (Point 32) and carried out some exploration work. Continental Minerals of Las Vegas has been exploring Sugarloaf Hill (Point 28) for gold mineralization.

Exploration and/or development activities for gold took place at the Black Bear (Point 25), Boswell (Point 31), Greenback (Point 26), Last Flat (Point 27), and Rainbow (Point 31) mines. □

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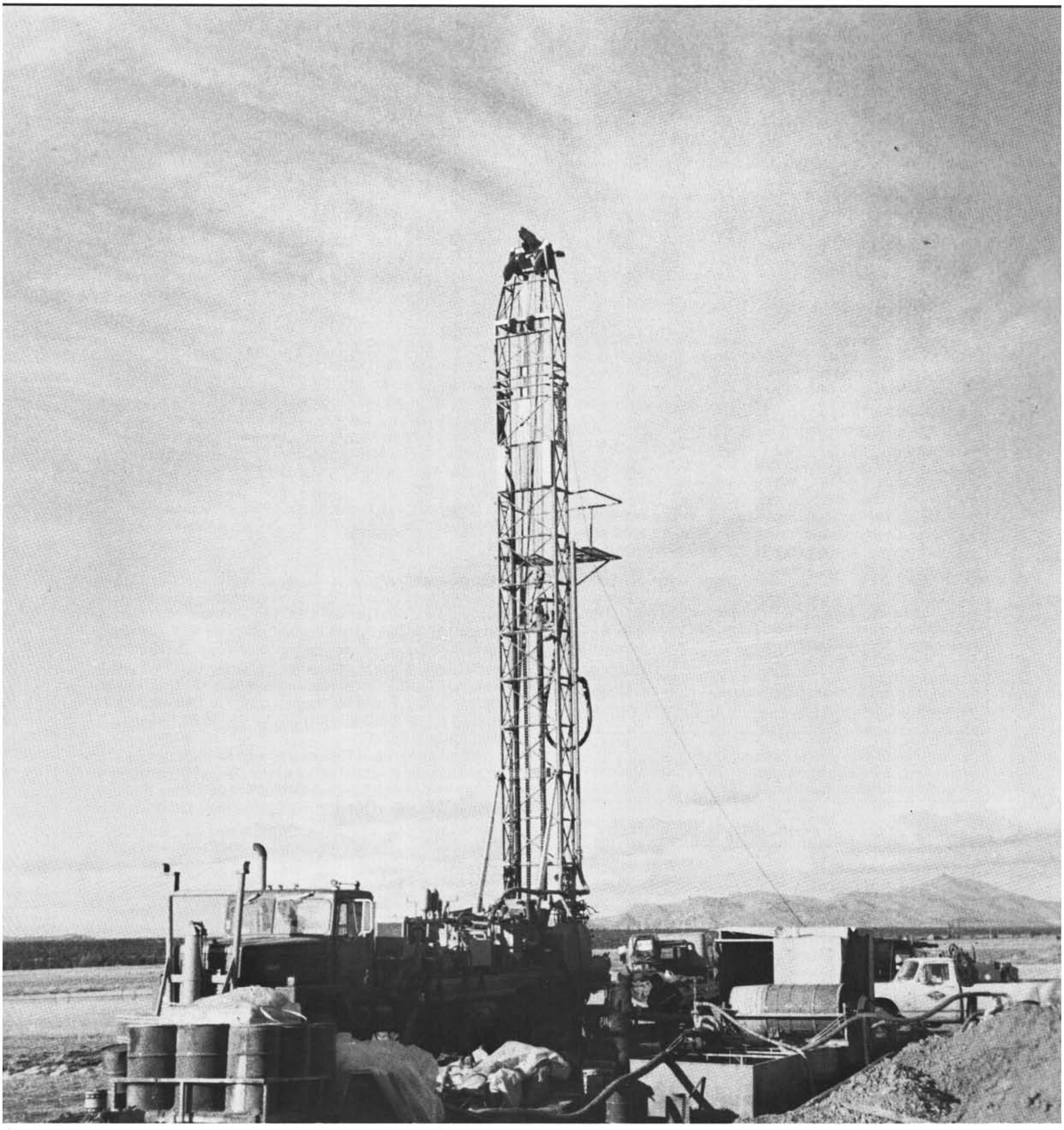

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COVER PHOTO

Powell Buttes 1, intermediate-depth geothermal gradient hole drilled for the Oregon Department of Geology and Mineral Industries on the west side of Powell Buttes, Crook County, by Janssen Drilling Co., Aloha. Drilled during the winter of 1980-81, the hole was suspended at 1,512 ft, with a bottom-hole temperature of 57°C (134°F). Article beginning on next page summarizes geothermal exploration activity in Oregon during 1980.

Geothermal open-file reports available

During 1979 and 1980, the Oregon Department of Geology and Mineral Industries (DOGAMI) conducted a U.S. Department of Energy/State of Oregon-funded low-temperature geothermal-resource assessment of nine areas in Oregon. Summaries of the results of studies in four areas are now available as open-file reports that contain raw and interpreted geothermal-gradient data, radiometric ages of selected rocks, chemical analyses of spring and well waters, calculated minimum reservoir temperatures, extensive bibliographies, and a variety of geological and geophysical maps.

Open-File Report 0-80-2 (Belknap-Foley area of the central Western Cascades) is 58 pages long, contains a two-color geologic map (scale 1:62,500), and sells for $5.00. Open-File Report 0-80-3 (Willamette Pass area of the central Western Cascades) is 65 pages in length, contains a two-color geologic map (scale 1:62,500), and also costs $5.00.

Open-File Report 0-80-6 (northern Harney Basin) is 52 pages long and has a two-color geologic map (scale 1:62,500) of the northern Harney Basin and gravity, aeromagnetic, and lineament maps (scale 1:250,000) of the entire Harney Basin.

Open-File Report 0-80-7 (southern Harney Basin) is 90 pages long and contains four two-colored geologic maps (scale 1:62,500) and an aeromagnetic map (scale 1:250,000) of the southern Harney Basin and aeromagnetic, gravity, and lineament maps (scale 1:250,000) of the entire Harney Basin. This report is available for $10.00.

DOGAMI has released the logs from Old Maid Flat well 7A as Open-File Reports 0-81-2A and 0-81-2B. The well is located west of Mount Hood and was drilled to a total depth of 6,027 ft. The reports contain directional surveys and fracture identification, temperature, variable density, dipmeter, sonic, gamma ray, formation density, and dual induction logs. Open-File Reports 0-81-2A and -2B may be purchased as one set for $100.00.

DOGAMI has also released 1978, 1979, and 1980 geothermal-gradient data for Oregon as Open-File Reports 0-81-3A, -3B, and -3C, respectively. The reports contain tabular and graphic compilations of temperature measurements and temperature gradients at depth intervals of 5 m. These data were collected from numerous wells throughout the State and then entered into GEOTHERM, the computerized information storage system maintained by the U.S. Geological Survey. The data were compiled for the Oregon Department of Geology and Mineral Industries by D.D. Blackwell, G.L. Black, and G.R. Priest under contract with the U.S. Department of Energy. Prices for the reports are as follows: 0-81-3A (1978, 63 p.), $4.00; 0-81-3B (1979, 98 p.), $6.00; and 0-81-3C (1980, 374 p.), $12.00.

All of these open-file reports may be inspected or purchased from the Portland office of the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, Oregon 97201. Orders for less than $20.00 must be prepaid. □

CONTENTS

Geothermal exploration in Oregon, 1980

by George R. Priest, Geothermal Specialist, and Dennis L. Olmstead, Petroleum Engineer, Oregon Department of Geology and Mineral Industries

ABSTRACT

Geothermal exploration continued at a moderate level in 1980, and acquisition of geothermal leases on Federal lands rose by 73 percent, generating about $1.5 million in revenue. Four geothermal wells (greater than 2,000 ft) and 127 prospect wells (less than 2,000 ft) were drilled in 1980. Five geothermal-well permits and 19 prospect-well permits were issued. No major new discoveries were reported, although plans continue to move ahead for geothermal-heating districts in Lakeview (Northwest Geothermal Corporation, with U.S. Department of Energy [USDOE]), Klamath Falls (private, State, and Federal funds), and Oakridge (probable Federal funding).

The Oregon Department of Geology and Mineral Industries (DOGAMI) continued its evaluation of geothermal resources by drilling 31 temperature-gradient holes, mapping, and performing chemical analyses of ground water in various parts of eastern Oregon and the north-central Cascades. DOGAMI recently drilled a 1,512-ft well southwest of Powell Buttes into a promising thermal anomaly which was discovered by the Department's geothermal group. A bottom-hole temperature of 57°C (134°F) was measured in the hole.

LEVEL OF GEOTHERMAL EXPLORATION

Most of Oregon's Known Geothermal Resource Areas (KGRA's) have been explored to some degree by government and industry. However, many broad areas with anomalous numbers of hot springs have yet to be investigated beyond the reconnaissance, or Phase-I, level (Figure 1).

Exploration of one of the main areas, the High Cascades province, has lagged behind all others. This area is environmentally sensitive and is composed of bed rock which has proven very difficult to drill. Furthermore, numerous industrial sources have indicated that slow processing of U.S. Forest Service leases has tended to inhibit further leasing in both the Western and High Cascades. The future of potential electric power development by industry in the High Cascades, where research by the Oregon Department of Geology and Mineral Industries has shown anomalously high heat flow, will depend upon ending the lease backlog in the U.S. Forest Service and solving the engineering problems associated with High Cascade drilling.

One exception to the above generalizations about industrial activity in the Cascades is the intense level of exploration by Sunoco Energy Development Company in the northwestern Cascades. Sunoco has been aggressively pursuing exploration of both the Breitenbush Hot Springs and Belknap-Foley Hot Springs areas for the past few years (Figure 1). In addition, Atlantic Richfield (ARCO) has begun preliminary work in the Oakridge-McCredie Hot Springs area near Willamette Pass (Figure 1).

DRILLING ACTIVITY

Type of drilling

Geothermal drilling by government and industry continued during 1980. Drilling of prospect wells (now defined by law as those wells less than 2,000 ft deep) continued at a reasonably high level, but drilling of geothermal wells (greater than 2,000 ft deep) was relatively minor (Figures 2 and 3; Tables 1 and 2).

Most of the activity continued to be focused on drilling of relatively cheap temperature-gradient holes, although an increasingly large proportion of these wells were drilled deeper than 500 ft. The tendency to drill somewhat deeper prospect wells is a reflection of two factors: (1) deeper wells have been found to yield superior temperature gradients in areas with porous sediments or in rocks with active shallow ground-water systems; and (2) many exploration programs have progressed to the point of intermediate-level (2,000-ft) drilling, now that shallow (500-ft) drilling arrays are complete. As thermal reservoirs become more completely defined, a larger number of deep wells (greater than 2,000 ft) will be drilled.

Table 1. *Geothermal permits and drilling activity in Oregon, 1980*

Permit no.	Operator	Well name	Location	Total depth (ft)	Status
70	U.S. Geological Survey	Pucci Chairlift	SE¼ sec. 7 T. 3 S., R. 9 E. Clackamas County	4,003	Deepened in 1980; suspended.
80	Chevron Resources Co.	Jordan 55	NW¼ sec. 9 T. 18 S., R. 43 E. Malheur County	2,820	Abandoned.
81	Northwest Natural Gas Co.	Old Maid Flat 7A	NE¼ sec. 15 T. 2 S., R. 8 E. Clackamas County	6,027	Suspended.
82	Oregon Dept. of Geology and Mineral Industries	Powell Buttes 1	SW¼ sec. 10 T. 16 S., R. 14 E. Crook County	1,512	Suspended.
83	Chevron Resources Co.	South Crump 46-4	Center sec. 4 T. 41 S., R. 24 E. Lake County	2,975	Suspended.

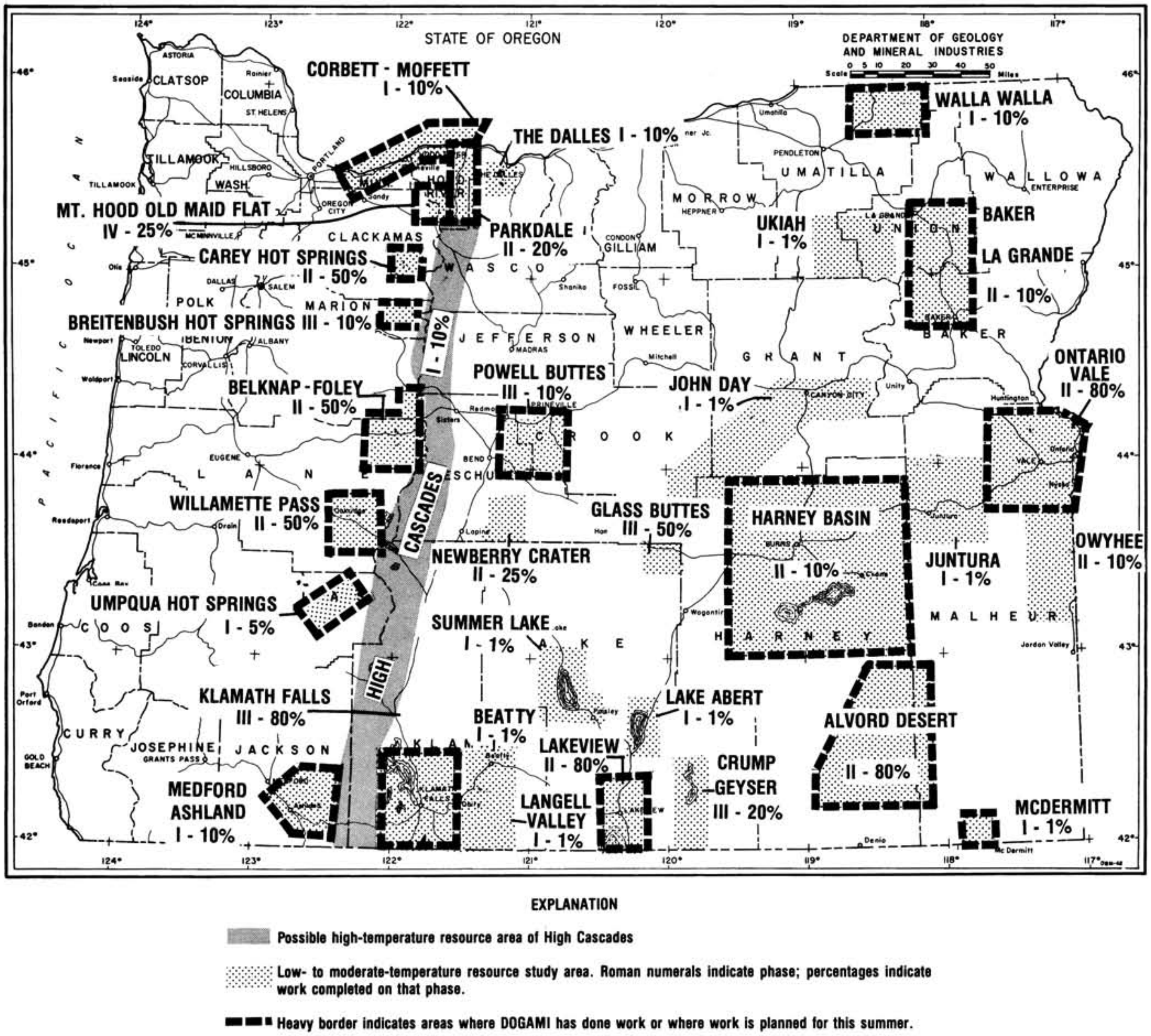


Figure 1. Exploration levels for geothermal resource areas in Oregon. Qualitative estimates of percent completed in each area are based on the following phase classifications: Phase I—reconnaissance work, no drilling. Phase II—shallow drilling of temperature-gradient wells. Phase III—intermediate- to deep-level drilling. Phase IV—deep drilling for reservoir assessment.

According to new Oregon law, holes deeper than 2,000 ft (versus 500 ft in the old law) are now considered geothermal production test wells. Shallower wells are considered prospect tests. This has greatly facilitated the process of obtaining permits for intermediate-level (500- to 2,000-ft) drilling. This may also be a factor in the increased percentage of 2,000-ft wells. The Department issued five geothermal-well permits (Table 1) and 19 prospect-well permits (Table 2) in 1980. A total of four geothermal wells and 127 prospect wells were actually drilled.

Government-sponsored deep drilling

The U.S. Department of Energy (USDOE) funded and managed a program of deep drilling and flow-testing for direct-use thermal water in Old Maid Flat, west of Mount Hood, on leases owned by Northwest Geothermal Corporation (Figure 5). This project involved drilling a 6,027-ft well (OMF-7A) and flow-testing it and a previously drilled 4,003-ft well (OMF-1). Very little thermal fluid was found in either hole, although temperatures were adequate for direct-use applications.

Utilizing USDOE funds, the U.S. Geological Survey (USGS) deepened the Pucci Chairlift hole (Figure 5) on Mount Hood from 2,000 to 4,003 ft and is conducting a flow test. Results of the flow test are not, as yet, complete, although J.H. Robison of the USGS has commented that the hydraulic head on the deep thermal water is not as high as was hoped.

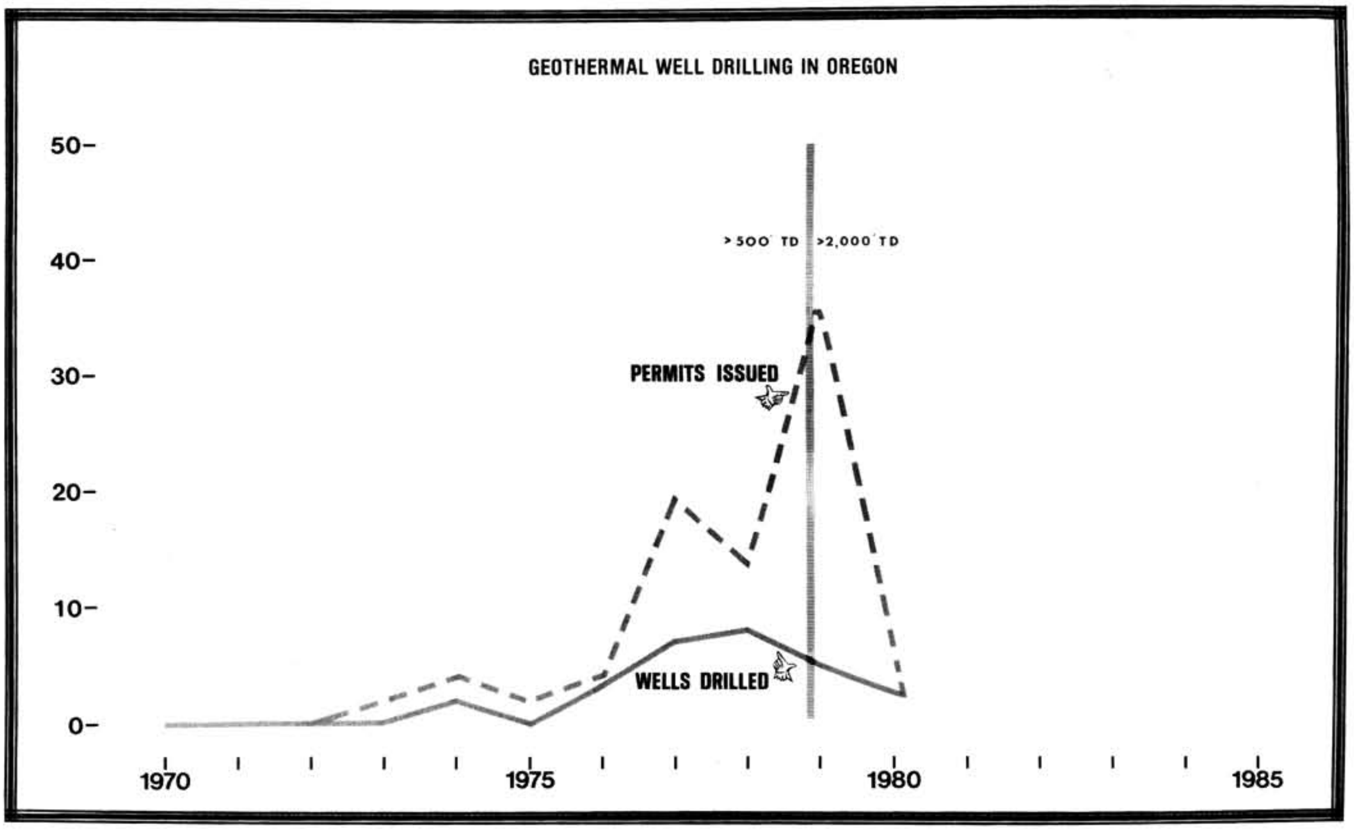


Figure 2. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 2,000 ft.

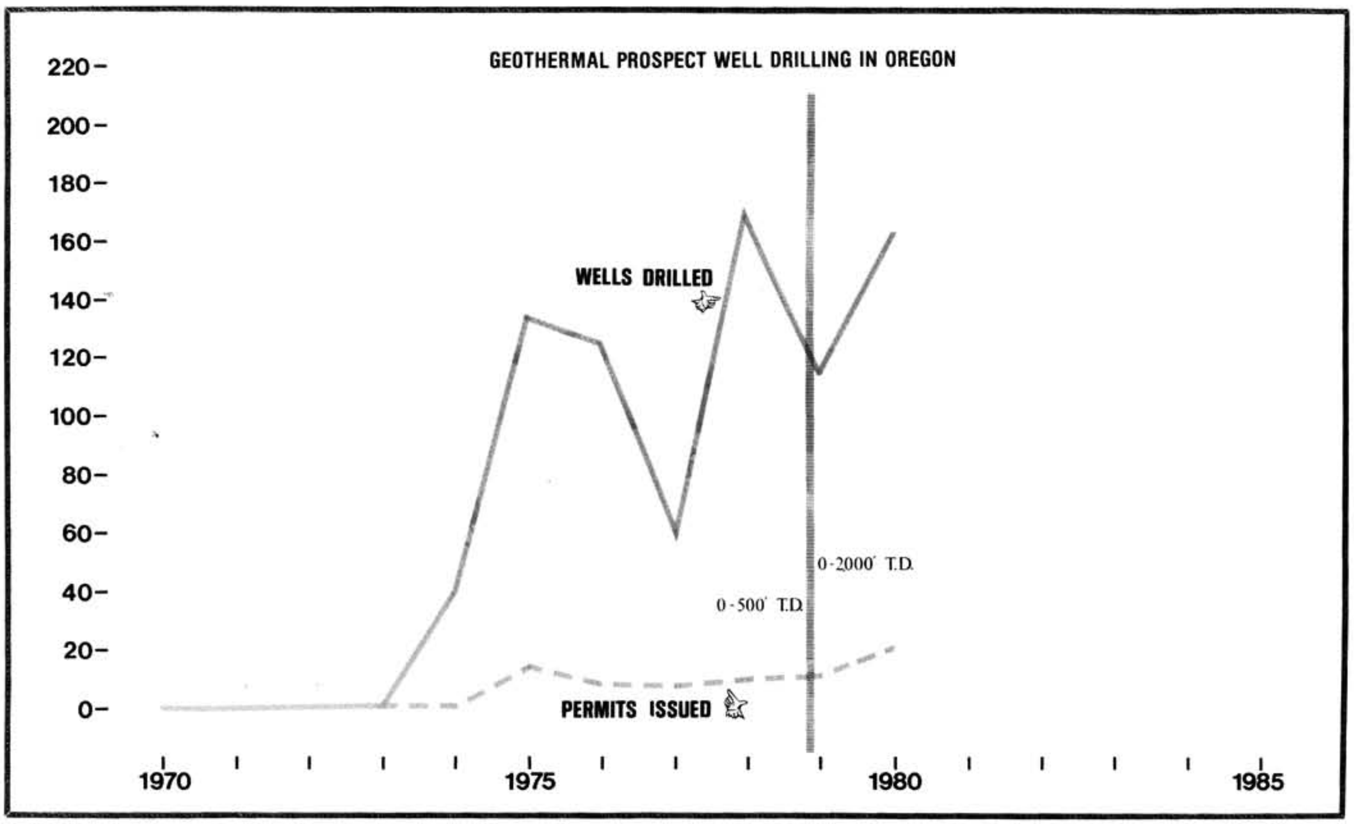


Figure 3. Geothermal prospect well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth less than 2,000 ft.

Table 2. *Geothermal prospect permits and drilling activity in Oregon, 1980*

Permit no.	Operator	Issue date	Location(s)	Comments and status
35	Sunoco Energy Development Co.	July 1979	Breitenbush and Belknap Hot Springs, Marion, Linn, Lane Counties	Drilled twenty-three 500-ft gradient holes.
50	Phillips Petroleum Co.	July 1979	Cox Flat Lake County	Drilled four gradient holes to 260 ft.
54	Oregon Dept. of Geology and Mineral Industries	Aug. 1979	Western Cascades Lane, Linn, Jefferson Counties	Drilled sixteen gradient holes to 500 ft.
55	U.S. Geological Survey	Aug. 1979	Mt. Hood area Clackamas County	Deepened one hole, drilled four holes, deepest to 1,163 ft.
58	Union Oil Co. of California	Sept. 1979	Alvord Desert Harney County	Drilled one hole to 2,000 ft.
62	Chevron Resources Co.	Feb. 1980	Alvord Desert Harney County	Program canceled.
63	Robert Dollar Co.	Mar. 1980	Klamath Lake Klamath County	Location, one gradient hole.
64	AMAX Exploration, Inc.	Mar. 1980	Bully Creek Malheur County	Program canceled.
65	Anadarko Production Co.	April 1980	Alvord Desert Harney County	Drilled eleven holes, deepest to 1,810 ft.
66	Phillips Petroleum Co.	May 1980	Glass Buttes Lake County	Drilled five holes, deepest to 1,945 ft.
67	Hunt Energy Corp.	June 1980	Lake Owyhee Malheur County	Drilled seven holes to 500 ft.
68	Oregon Dept. of Geology and Mineral Industries	June 1980	Parkdale Hood River County	Location, three gradient holes.
69	Chevron Resources Co.	June 1980	Warner Valley Lake County	Drilled twenty-one holes to 500 ft.
70	Chevron Resources Co.	June 1980	Warner Valley Lake County	Drilled nine holes to 500 ft, one to 2,000 ft.
71	Oregon Dept. of Geology and Mineral Industries	Aug. 1980	Oakridge Lane County	Deepened one hole to 1,130 ft, drilled one to 500 ft.
72	Phillips Petroleum Co.	Sept. 1980	Cox Flat Lake County	Drilled three holes, deepest to 1,555 ft.
73	Oregon Dept. of Geology and Mineral Industries	Nov. 1980	Hood River Valley Hood River County	Location, four gradient holes.
74	Oregon Dept. of Geology and Mineral Industries	Nov. 1980	Powell Buttes Crook County	Drilled eight holes to 500 ft.
75	Oregon Dept. of Geology and Mineral Industries	Nov. 1980	Burns area Harney County	Drilled four holes, deepest to 615 ft.

Industrial deep drilling

Chevron Resources Company was the only company involved in significant deep drilling (below 2,000 ft). They lost a 2,820-ft well near Vale and completed a 2,979-ft well at Crump Lake, near Lakeview (Figure 1). Both wells were drilled for high-temperature fluid to generate electricity.

LEASING

The level of geothermal leasing increased dramatically in 1980. There was a 73 percent increase in leased Federal acreage, most of which was non-KGRA land (Table 3). No accurate data are available for private leases, but a similar increase probably occurred in that sector as well. This dramatic increase in leasing may herald a major increase in exploration efforts for the next few years.

Three U.S. Bureau of Land Management (USBLM) lease sales were held in 1980. Anadarko Production Company, Union Oil Company, Intercontinental Energy Corporation, Hunt Oil Company, Getty Oil Company, Chevron Resources, and Al-Aquitaine Exploration bid a total of $1,530,692.34 on 32,641 acres of land in KGRA's (Table 4). No further lease sales are planned for 1981.

Most geothermal leases continue to be located in either the Basin and Range province of southeastern Oregon or the Western Cascades of northwestern Oregon. The most extensive holdings are at the following areas: Vale-Owyhee, Alvord Desert, Crump Geyser, Lakeview, Paisley, Klamath Falls, Newberry Caldera, Belknap-Foley Hot Springs, Breitenbush

Table 3. *Geothermal leases, 1980*

Type of leases	Net gain since 1979 Numbers		Net gain since 1979 Acres		Relinquished since 1979 Numbers	Relinquished since 1979 Acres
Federal leases						
Noncompetitive, USBLM	76	(+67%)*	41,709.81	(+74%)*	2	2,566.58
Noncompetitive, USFS	2	(+12%)*	1,282.36	(+ 3%)*	0	0
KGRA, USBLM	16	(+76%)*	30,280.75	(+70%)*	3	6,322.56
KGRA, USFS	0		0.00		0	0
Total	94	(+58%)*	73,272.92	(+73%)*	5	8,889.14
Federal leases pending						
Noncompetitive, USBLM	36	(+29)*	72,955.50			
Noncompetitive, USFS	73	(+20)*	156,069.81			
KGRA, USBLM	1		2,360.00			
KGRA, USFS	0		0.00			
Total	110	(+23%)*	231,385.31			
State						
Total leases active in 1980	13		9,687			
Total applications pending	3		2,010			
Private						
Total leases active (est.)	No data		~250,000			

* Based on total of all leases as of 1-2-80.

Table 4. *1980 U.S. Bureau of Land Management KGRA sales*

Tract no.	Date (1980)	Company	Area	Acreage	Amount ($)
13	Jan. 8	Anadarko Pro. Co.	Alvord	2,280	$ 236,367.60
14	Jan. 8	Anadarko Pro. Co.	Alvord	2,463	90,605.33
33	Jan. 8	Union Oil	Breitenbush	1,040	10,341.45
39	Jan. 8	Intercontinental	Klamath Falls	119	917.53
50	Jan. 8	Hunt Oil	Crump Geyser	2,371	4,833.35
51	Jan. 8	Hunt Oil	Crump Geyser	2,344	4,828.58
4	April 29	Getty Oil	Alvord	2,563	30,117.37
28	April 29	Getty Oil	Alvord	1,830	61,751.70
29	April 29	Getty Oil	Alvord	2,542	44,478.35
33	April 29	Anadarko	Alvord	2,400	149,664.00
34	April 29	Anadarko	Alvord	2,560	397,516.80
35	April 29	Getty Oil	Alvord	40	630.00
36	April 29	Anadarko	Alvord	2,520	227,379.60
37	April 29	Getty Oil	Alvord	2,560	44,802.28
59	April 29	Chevron	Crump Geyser	2,568	5,785.00
60	April 29	Chevron	Crump Geyser	81	1,057.00
1	Oct. 23	Al-Aquitaine Explor.	Alvord	2,360	249,617.20
			Total	32,641	$1,530,692.34

Hot Springs, Austin (Carey) Hot Springs, and Mount Hood.

Atlantic Richfield (ARCO) has acquired a significant land position around the Kitson-McCredie Hot Springs area. This is the first time ARCO has shown interest in the Cascades, and they plan to do preliminary geophysical and geological studies and water sampling in this area during the upcoming field season.

Northeastern Oregon and the Ashland-Medford area continue to be largely ignored by industry, although both areas have low- to moderate-temperature geothermal resources. This may be blamed on the general tendency for most larger companies to concentrate on high-temperature resources for electrical power production.

RESEARCH

Low-temperature geothermal resources

The Department is continuing its USDOE-funded low-temperature geothermal-resource assessment program. The second year of this study has culminated in preparation of resource assessment open-file reports on the following areas (Figure 1):

- Belknap-Foley—Open-File Report 0-80-2*
- Willamette Pass—Open-File Report 0-80-3*
- Craig Mountain-Cove (La Grande)—Open-File Report 0-80-4
- Western Snake River Plain (Vale)—Open-File Report 0-80-5
- Northern Harney Basin (Burns)—Open-File Report 0-80-6*
- Southern Harney Basin—Open-File Report 0-80-7*
- Powell Buttes—Open-File Report 0-80-8
- Lakeview—Open-File Report 0-80-9
- Alvord Desert—Open-File Report 0-80-10

* Already available for sale from the Portland office of the Oregon Department of Geology and Mineral Industries.

All of these reports contain compilations of chemical analyses of spring and well waters, reservoir-temperature calculations, temperature-gradient measurements, calculated heat flow, and all available geologic and geophysical maps of each area. New, previously unpublished data in nearly every category have been either generated by the Department or borrowed from industrial sources. All of these studies are, as yet, preliminary and will be complemented by final reports of the most promising areas.

Considerable drilling was also completed under the low-temperature assessment program. In 1980, 13 holes were drilled for temperature-gradient measurements to depths of less than 600 ft. These prospect wells were drilled near Oakridge (Figure 6), Burns (Figure 7), and Powell Buttes (Figure 8). The Oakridge city well was deepened from 420 to 1,130 ft, and one well (PB-1) has just been completed to a depth of 1,512 ft into a thermal anomaly at Powell Buttes (Figure 8). This thermal anomaly, discovered by the Department in 1978, is marked by temperature gradients as high as 164°C/km (527°F/mi). A bottom-hole temperature of 57°C (134°F) in the 1,512-ft hole indicates that high gradients extend at least to that depth. This hole will be deepened if funds can be found.

The Department plans to do limited shallow (500-ft) drilling of temperature-gradient wells in the Parkdale area northeast of Mount Hood and in the Corbett-Camp Collins area near Portland in 1981 if funds are available.

Cascades study

The Department has continued to pursue geothermal research in the north-central Cascades with support from USDOE. Sixteen shallow (500-ft) temperature-gradient wells were drilled during 1980 to complete the program of 22 holes (Figure 9). Raw temperature-gradient data for these wells and all other wells probed by DOGAMI in Oregon since 1978 are available as Open-File Reports 0-81-3A (1978 data), 0-81-3B (1979 data), and 0-81-3C (1980 data).

Detailed geologic mapping and K/Ar dating was accomplished by the Department as part of the Cascades study in 1979 and 1980. Most of the mapping effort was focused on the following areas: (1) Devil's Creek area near Breitenbush Hot Springs, (2) Cougar Reservoir area at Terwilliger Hot Springs, (3) Southern Lookout Point Reservoir, and (4) Pinto Creek-Tumblebug Creek area near Diamond Peak. A geologic map (scale 1:24,000) of the Cougar Reservoir area will be published during the spring or summer of 1981, and a brief geological summary was presented at the annual Oregon Academy of Science meeting on February 28, 1981.

The Department has also supervised several subcontracted studies of the Oregon Cascades with USDOE support. C.M. White of Boise State University completed a study published as the *Geology of the Breitenbush Hot Springs Quadrangle, Oregon* (DOGAMI Special Paper 9). J.R. Magill and A.V. Cox of Stanford University summarized paleomag-

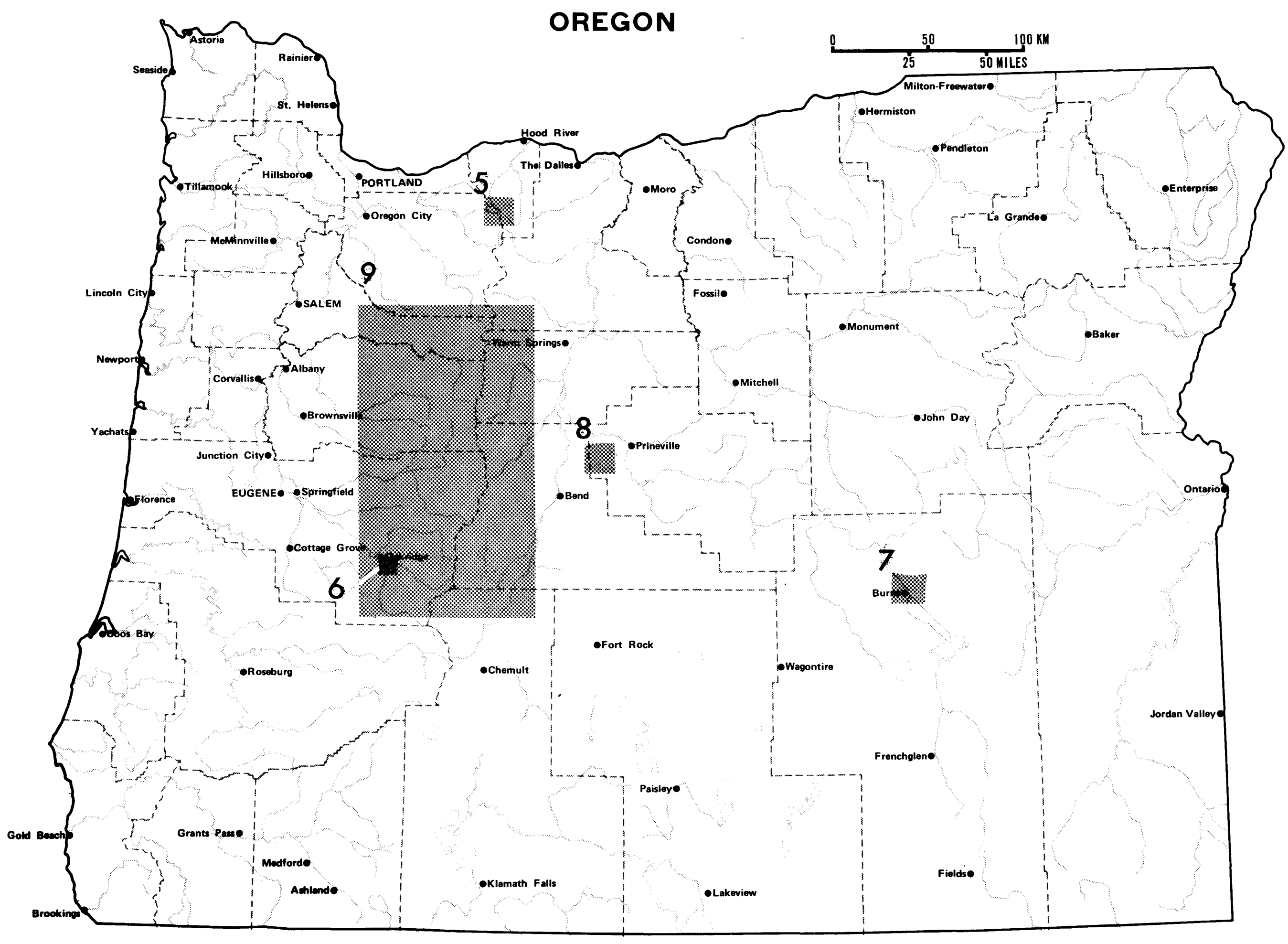


Figure 4. Map showing locations of areas covered by Figures 5, 6, 7, 8, and 9.

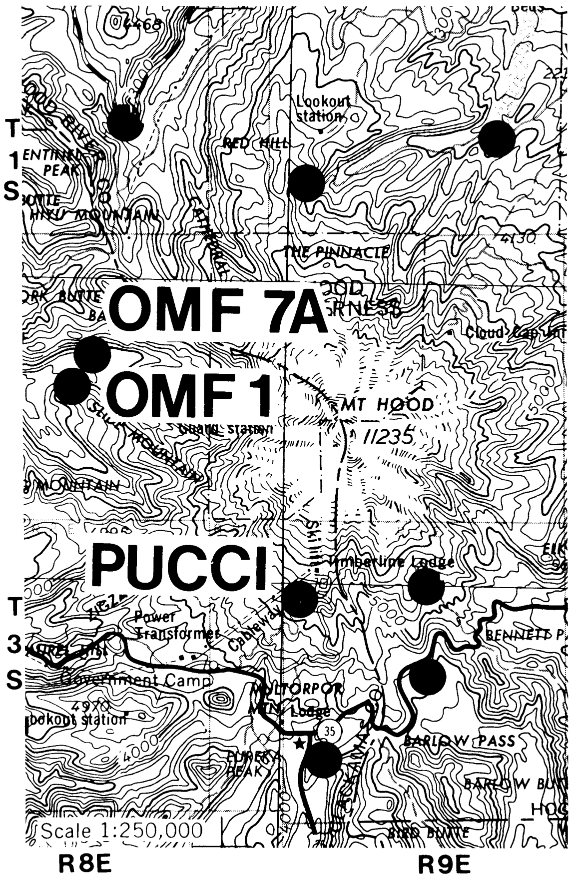


Figure 5. Geothermal drilling in the Mount Hood area, 1980. The Pucci Chairlift hole and unlabeled holes were drilled by the USGS. The Pucci hole was deepened from 2,000 to 4,003 ft. The OMF-1 hole was flow-tested and abandoned by the USDOE. OMF-7A was drilled by the USDOE to 6,027 ft.

netic data on the Cascades in their paper *Tectonic Rotation of the Oregon Western Cascades* (DOGAMI Special Paper 10). The Oregon State University Geophysics Group has completed a regional gravity and aeromagnetic survey of the entire Oregon Cascades, which will be released this spring as part of the Department's Geological Map Series. C.W. Field and S.G.P. Storch of the Oregon State University Department of Geology are working on a summary report on ancient hydrothermal systems of the Western Cascades. Foundation Sciences is currently finishing a lineament study of the southern Cascades to complement the recently published DOGAMI Special Paper 12, *Geological Linears of the Northern Part of the Cascade Range, Oregon*, by R. Venkatakrishnan, J.G. Bond, and J.D. Kauffman.

Old Maid Flat 1, Clackamas County

The Northwest Geothermal Corporation's deep exploratory well, Old Maid Flat 1, located in the SE ¼ SW ¼ sec. 15, T. 2 S., R. 8 E., at Old Maid Flat west of Mount Hood (Figure 5), was completed to a depth of 4,003 ft in 1978 and flow-tested in June 1980. Funding for drilling and testing was provided primarily by USDOE. No significant fluid was recovered from the well, and it was plugged and abandoned. A complete set of geophysical logs for OMF-1, including temperature data, is available from the Oregon Department of Geology and Mineral Industries as Open-File Report 0-78-6.

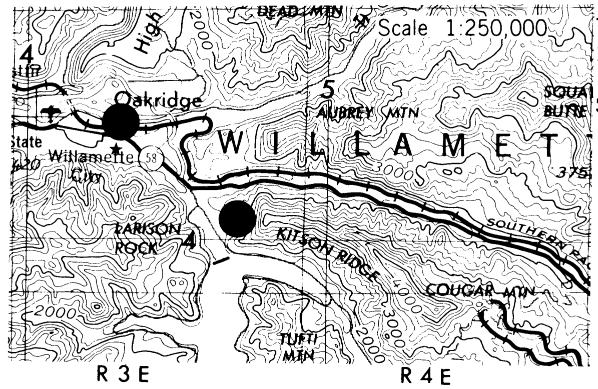


Figure 6. Geothermal drilling, Willamette Pass-Oakridge, 1980. Two holes were drilled in this area by the Oregon Department of Geology and Mineral Industries under the USDOE low-temperature geothermal-resource assessment program. The Oakridge city well was deepened to 1,130 ft, and a 500-ft temperature-gradient well was drilled south of town.

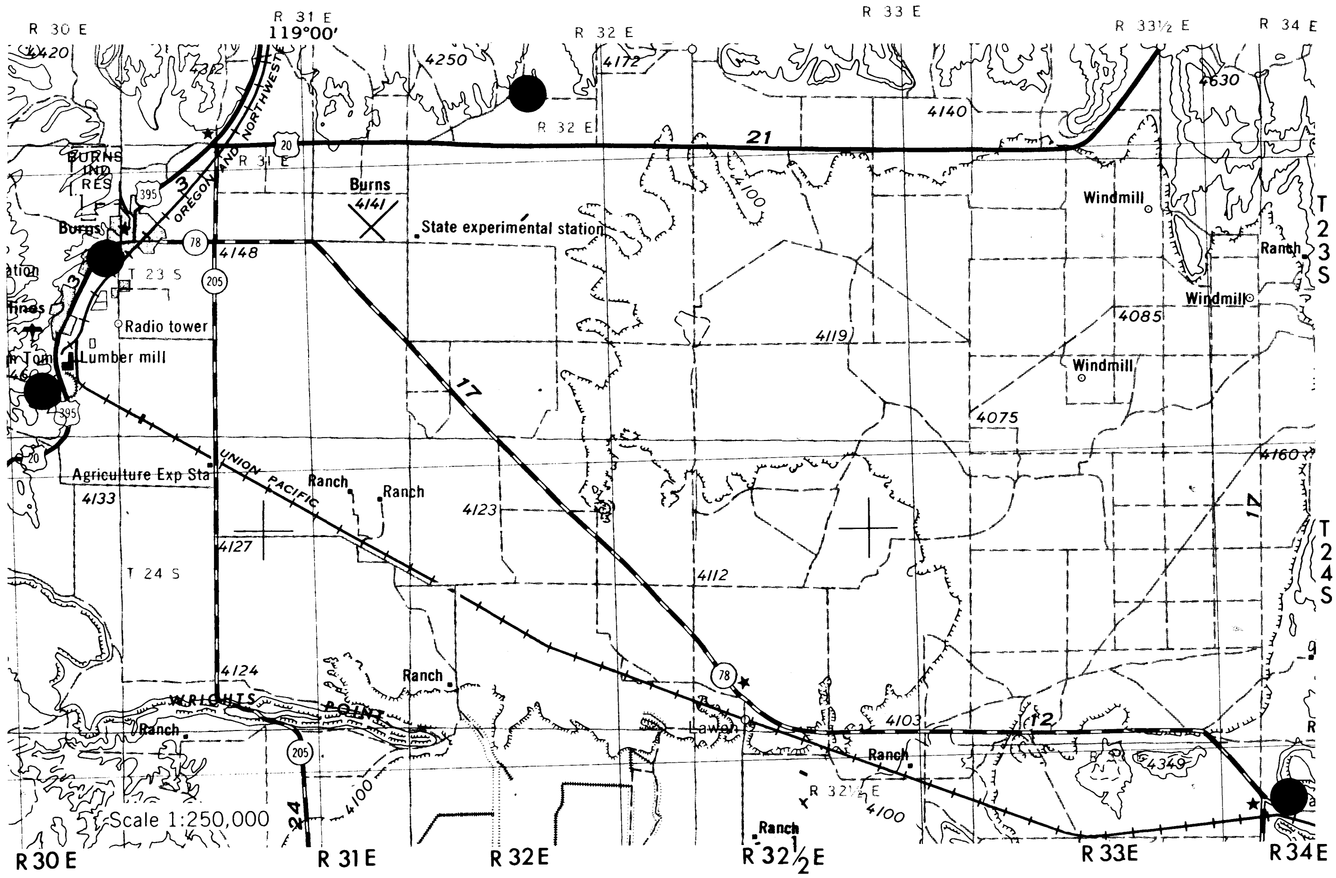
Old Maid Flat 7A

The USDOE-State-coupled geothermal exploration program for low-temperature direct-use geothermal water funded the drilling of a deep (6,027-ft) test well at Old Maid Flat, west of Mount Hood. The Old Maid Flat 7A test well (OMF-7A, Figure 5), located in the SW¼ NE¼ sec. 15, T. 2 S., R. 8 E., at an elevation of 2,760 ft, was completed in October 1980. The property is under lease by Northwest Geothermal Corporation, an affiliate of Northwest Natural Gas Corporation.

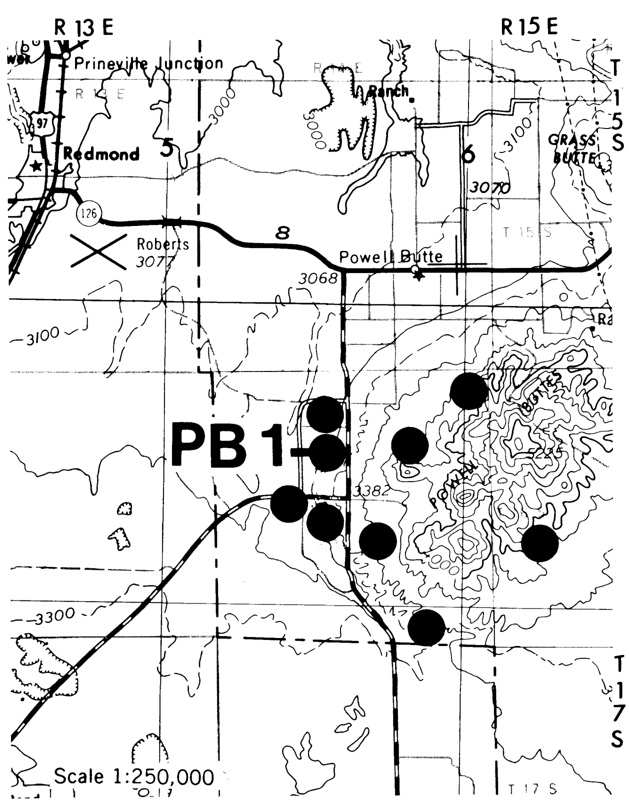
The well was designed to test the reservoir characteristics of the Columbia River Basalt Group where that unit is intercepted by a normal fault. The hole was drilled at 24 in. to 96 ft and lined with 18-in. casing, then drilled to 1,191 ft at 14.75 in. and lined with 10.75-in. casing. The well was rotary-drilled at a diameter of 9.88 in. to 6,011 ft and diamond-drilled at 4 in. to 6,027 ft. Other diamond cores were also drilled at 1,595 to 1,624 ft, 2,914 to 2,920 ft, 3,381 to 3,399 ft, 4,394 to 4,417 ft, and 5,122 to 5,152 ft. All cores and cuttings are available for examination at the Oregon Department of Geology and Mineral Industries in Portland.

Approximately 6,000 ft of 2.88-in. temperature observation pipe was put in the hole after flow tests proved disappointing (less than one gallon per minute from all thermal aquifers). The hole will be plugged and abandoned by August 31, 1981, if no further uses can be found for it. It is hoped, however, that some scientific purpose such as geophysical monitoring will be found for this very expensive well. DOGAMI and M.H. Beeson of the USGS are now seeking groups interested in scientific uses for this hole.

A complete suite of Schlumberger geophysical logs and lithologic logs is available for Old Maid Flat 7A as Open-File Reports 0-80-11, 0-81-2A, and 0-81-2B. In addition, M.J. Holdaway of Southern Methodist University is preparing a complete analysis of alteration mineralogy encountered, and M.H. Beeson of Portland State University will analyze samples from all the volcanic units for both major- and trace-element composition. D.D. Blackwell of Southern Methodist University is measuring various geophysical parameters of cores and cuttings for quantitative correlation to the geophysical logs. Publications summarizing these investigations and some geological work by the Department will be available some time in the summer or fall of 1981.



↑ *Figure 7. Geothermal drilling, Harney Basin, 1980. Drilling of 500- to 600-ft temperature-gradient wells was undertaken by the Oregon Department of Geology and Mineral Industries as part of the USDOE low-temperature geothermal-resource assessment program.*



USGS exploration at Mount Hood

With the support of USDOE funds, the USGS completed an ambitious program of intermediate to deep geothermal drilling around Mount Hood this last fall (Figure 5). The exploration program was managed by J.H. Robison and focused on fluid chemistry, temperature gradients, and stratigraphic analysis. M.H. Beeson of the USGS will conduct an analysis of hydrothermal alteration in the holes at Mount Hood and other parts of the Cascades.

Four holes were drilled around the flanks of Mount Hood this season to depths of 800 to 2,000 ft (Figure 5). In addition, the Pucci Chairlift hole near Timberline Lodge was deepened to 4,003 ft and tested for recharge in the thermal zone (see section on government-sponsored deep drilling). The thermal water table is 1,891 ft below the surface. Temperature gradients vary from 30° to 84°C/km (138° to 295°F/mi); temperature in the production zone is expected to be more than 70°C (158°F). A production test is planned for 1981.

← *Figure 8. Geothermal drilling, Powell Buttes, 1980. Temperature-gradient wells, 500 ft and one 1,500 ft (PB-1), were drilled by the Oregon Department of Geology and Mineral Industries as part of the USDOE low-temperature geothermal-resource assessment program.*

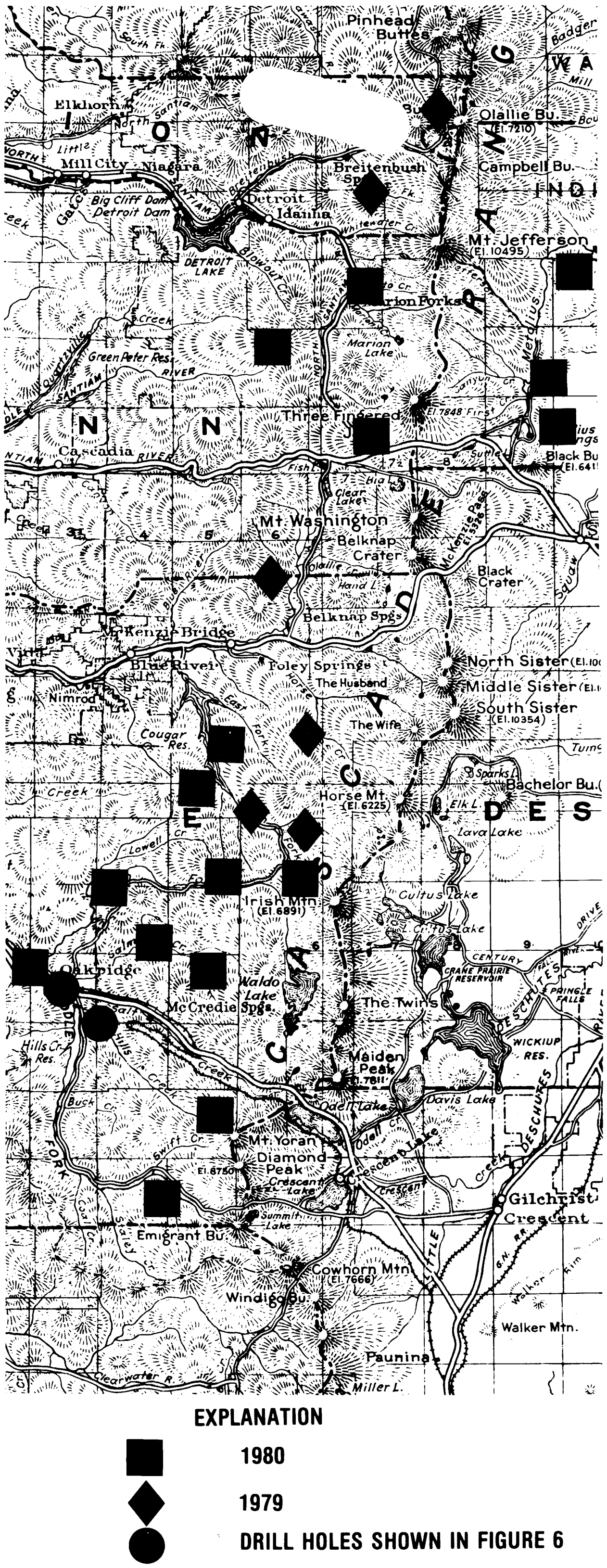


Figure 9. DOGAMI Western Cascades geothermal-resource study, 1979-1980. Map shows locations of 500-ft temperature-gradient wells drilled as part of the USDOE geothermal-resource assessment of the Cascades. Also indicated are holes drilled for the low-temperature geothermal-resource assessment program (see Figure 6).

USGS exploration in the central and southern Oregon Cascades

Most of the USGS work in the central and southern Cascades of Oregon has centered on the young and potentially active volcanic centers at Crater Lake and Newberry Caldera. Crater Lake work has included heat-flow measurements in bottom sediments, water sampling, seismic reflection profiling, and detailed mapping of the wall of the caldera. Geophysical work is under the coordination of D.L. Williams of the Denver, Colorado, office; and C.R. Bacon of the Menlo Park, California, office is conducting the geologic investigation.

The geothermal evaluation of Newberry Caldera has been supervised by N.S. MacLeod of the Menlo Park office. He has completed mapping and is currently conducting petrochemical and isotopic studies. During 1979, hydrologic and heat-flow studies including drilling of two holes, 2,100 and 2,000 ft deep, in the caldera. One of these holes was lost because of drilling problems during that year, but the other will be deepened in 1981, according to a recent USGS newsletter.

Publication last year of USGS Professional Paper 1044-G, *Hydrogeologic Appraisal of the Klamath Falls Geothermal Area, Oregon*, by Edward A. Sammel was a major contribution to the understanding of the Klamath Falls geothermal system. Sammel will also be involved in evaluation of the Newberry hydrologic system.

Oregon Institute of Technology

The Oregon Institute of Technology (OIT) continues to operate the Geo-Heat Utilization Center to further the development of geothermal energy in the Pacific Northwest. The Center can provide up to 100 hours or $5,000 of free geothermal consultation on direct-heat applications. The Center has published a great deal of information about the use of geothermal energy and the state of geothermal development in the Northwest as part of its regional coordination program for the northwestern United States. The Geo-Heat Center will select twelve communities for major heating-district feasibility studies this spring. This program is above and beyond the 100-hour consultation program and will be focused on municipalities with known resources that have little possibility of industrial support.

The Geo-Heat Center has recently given consultation help to Northwest Geothermal Corporation on their heating-district project for Lakeview. Similar consultations have been given to various groups in Klamath Falls, La Grande, Vale, and Oakridge. All of these cities are moving ahead into exploratory phases of heat utilization as funding is secured. □

OMSI announces summer paleoecology program

The Oregon Museum of Science and Industry is preparing a summer program designed to introduce high school students to the paleobotany and vertebrate paleontology of Tertiary geologic units in the John Day basin of central Oregon. The National Science Foundation-supported program will include team field projects, individual studies, and lectures. The eight-week course starts June 19, 1981, and will be based at OMSI's Hancock Field Station, Fossil, Oregon. The $650 tuition covers cost of food, lodging, transportation, and instruction. Financial-need scholarships are available. Interested persons should contact Bruce Hansen, Research Center, OMSI, 4015 S.W. Canyon Road, Portland, Oregon 97221. □

Surface mined land reclamation in Oregon, 1980

by Paul F. Lawson, Supervisor, Mined Land Reclamation Program, Albany Field Office, Oregon Department of Geology and Mineral Industries

During 1980, Oregon's program for the reclamation of surface mined land continued to evolve. The number of professional staff of the Mined Land Reclamation Program fluctuated between one and three during the year, with three at year's end. With this field staff and with office support of one clerical specialist and one part-time clerical assistant, 681 field inspections were conducted and recorded, and in most cases other actions concerning the sites were accomplished.

Of particular satisfaction is the observation that several sizable sites have been or are being reclaimed on a volunteer basis. These are sites where either mining was completed before the law existed or the area was exempted from mandatory reclamation under the provisions of ORS 517.770(1)(a)(c). All of these sites are expensive investments. One is a landscaped lake-park completed by a city for esthetic and safety reasons. The others were done by private enterprise for the enhancement of real estate and profit. The existence of these voluntarily reclaimed sites illustrates a growing awareness of the values of reclamation—an attitude that is in strong contrast to the past practices of either abandoning the land or reclaiming it only because the law required it. This growing awareness is leading to more cooperation with the program's goals: to extract needed mineral resources, to leave the mined site reasonably safe and nonpolluting, and to achieve a future "beneficial use" for the mined land, thereby desirably enhancing its value.

The costs of reclamation continue to escalate. Another State of Oregon agency which frequently does the same kinds of tasks required for surface mined land reclamation quotes figures charged it by contractors for fertilizing, seeding, and mulching—not including contouring or seed-bed preparation. For areas over 5 acres and in conjunction with a larger contract, quotations slightly exceed $500 per acre. When the acreage is less than 5 acres and the job is not part of a larger contract, quotations reach $1,000 per acre. A large amount of detailed data assembled from the Bureau of Land Management, the U.S. Forest Service, and commercial sources further forcefully illustrates the rising costs of services and equipment. From this it is apparent that the Department must take action to insure that bonding to guarantee reclamation keep pace with costs, that reclamation be carefully planned even prior to the beginning of mining to insure the most economical practices, and that all details of reclamation be appropriate to the site.

Not surprisingly, a substantial proportion of new sites are gold placers. By their nature and usually by location as well, placer operations have an inherent capacity to turn many yards of earth into a "mud soup" in the nearest stream. Yet, in most cases, it is possible for a reasonably careful operator to wash for gold with a closed, recirculating system of reservoir and settling ponds without affecting a nearby watercourse.

CURRENT STATUS

The following figures and data depict the present scope and trends of Oregon's Mined Land Reclamation Program.

As of December 31, 1980, a total of 443 acres had been reclaimed. Of that total, acreage was reclaimed for the following uses as indicated: agriculture, 251 acres; forestry, 7 acres; housing, 37 acres; and other,* 148 acres. Of the 443 acres, 106 acres were reclaimed in 1980. Not included with these figures, because it is impossible to keep up to date, is additional concurrent reclamation completed within sites still operating.

As of December 31, 1980, 2,173 acres are under security with approved reclamation plans on 269 sites. Many of these sites contain additional grandfathered acreage. Experience indicates that some of the grandfathered acreage will be reclaimed voluntarily.

Of the total "bonded" acreage, 84 percent is secured by performance bonds; the remainder is secured by various other types of security.

Because of the inflation in reclamation costs, bonds for 73 percent of all sites with reclamation requirements have been brought up to the authorized ceiling of $500 per acre, as opposed to 45 percent at the beginning of 1980. Nearly 17 percent of reclaimable sites are bonded at around $300 per acre. The remaining 10 percent are bonded at several levels above and below $300 per acre. Bonding on most sites will increase to the present ceiling; however, rates per acre may be expected to be reduced on sites where reclamation is substantially underway.

In order to insure that adequate funds will be available to guarantee reclamation in the event the operator defaults, the Department is seeking an increase to $1,500 in the authorized bonding ceiling. The maximum would not be assessed against every site. Such a ceiling will insure a greater likelihood that, if necessary, the State can pay for the reclamation the operator contracted to perform. It will perhaps further encourage concurrent reclamation, as the total bond may be reduced at each year's review if the net affected acreage decreases.

Presently operating sites with reclamation plans have lands scheduled to be reclaimed to the following uses: agriculture, 125 sites; forestry, 63 sites; housing, 23 sites; and other,* 88 sites. These figures exceed the total number of sites with reclamation plans because some sites will reclaim lands in more than one category.

In 1980, 46 new surface-mining permits (requiring reclamation plans) were issued, and 19 surface-mining permit sites were closed, reclaimed. Thirty-four new limited-exemption (grandfathered) sites were opened; four were closed. Forty-six new total-exemption sites were opened; three were closed. A few sites changed status from one to another of the above categories.

At year's end, there were 333 sites permitted under Grants of Limited Exemption and 571 sites under Grants of Total Exemption.

* "Other" as used above includes water impoundments (for recreational fishing, irrigation, stock pond, commercial aquaculture, marina, etc.), fish and duck hunting preserve, landfill, demolition disposal, industrial-commercial construction sites, log deck sites, wildlife management, stockpile site, and one fossil collecting site. □

Correction

The name of Morse Brothers, Inc., was placed in the wrong sentence in the last paragraph on page 34 in the March 1981 issue of *Oregon Geology*. The sentences should have read: "Limestone marketing in the Willamette Valley has been changed by the importation by barge of limestone from Texada Island, B.C., to Newport (Point 7) by Morse Brothers, Inc. Prior to this time, limestone was supplied to the valley by barge from Texada Island to Portland, then south by rail." □

Comment and Reply on "The petrology and stratigraphy of the Portland Hills Silt—a Pacific Northwest loess"

Comment

Roger B. Parsons, West Technical Service Center, Soil Conservation Service, U.S. Department of Agriculture, 511 N.W. Broadway, Portland, Oregon 97209

I read with interest and general agreement the article by R.T. Lentz about the Portland Hills Silt in the January 1981 *Oregon Geology* (v. 43, no. 1, p. 3-10). However, some of the questions remaining unstudied and unanswered are:

1. Why does the Portland Hills Silt, if loess, thin from 80 to 120 in. on stable summits of the Chehalem Mountains to 0 on the Red Hills of Dundee only about 4 mi to the southwest? Theisen and Knox (1959) and Lentz limited the areal extent of their studies, and apparently recon, to the Chehalem-Tualatin Mountain areas. In most "loess" studies, the work has covered larger areas. Why is there no loess on the Red Hills of Dundee, Salem Hills, etc.? Generally, loess does not thin so drastically on stable summits (Eola geomorphic surface).

2. The 14C age of 34,410 ± 3,450 y.a. reported by Glenn (1965) came from organics in sediments under the early Holocene Winkle geomorphic surface, not the Calapooyia surface—the late Pleistocene main valley floor. All wood samples we have obtained from the Willamette Formation under the Calapooyia surface have been beyond reach of 14C dating techniques.

3. The Irish Bend Member of the Willamette Formation (Balster and Parsons, 1969) near St. Paul has bedding with a dip and strike toward the Chehalem Mountains, suggesting post-late Pleistocene upwarp. The Irish Bend usually has horizontal bedding. Early Holocene stream displacement has been documented in the area (Parsons, 1969).

4. There are two unconforming fragipans in the Tualatin Mountains that are not coextensive with the upper soil horizons (an umbric epipedon and a cambic) or the ground surface. The mineralogy and particle size of two silt units was reported by Whittig and others (1957). It is unfortunate Lentz did not review and cite this work.

5. As yet there is no explanation of why the erratic (exotic if from the Troutdale Formation) pebbles in the Portland Hills Silt so often occur at the contact between the cambic (B) horizon and the fragipans (IICx or Bx horizons). Is it possible the pebbles are a stoneline? Stonelines have been observed in the paleosol under the silt.

6. To date there is no known reason why Laurelwood soils (Ultic Haploxeralfs, fine-silty, mixed, mesic) on the Chehalem Mountains lack fragipans, while Cascade soils (Typic Fragiumbrepts, fine-silty, mixed, mesic) just across the Tualatin Valley syncline have fragipans. Supposedly the "loess" is the same, yet the soil-stratigraphy is different.

Perhaps we should, at least briefly, entertain the thought that the Portland Silts, due to their limited areal extent to the southwest plus problems listed above, could be displaced, reworked former Irish Bend-like (formerly Willamette Silts) sediments.

The area could use a coordinated soil-geologic project to resolve some of these remaining questions.

January 29, 1981

Reply

Rodney T. Lentz, Bureau of Land Management, P.O. Box 194, Battle Mountain, Nevada 89821

Thank you for the opportunity to respond to some of the questions raised by Dr. Parsons. I'm glad the article has surfaced an interest in the Portland Hills Silt (PHS) by the soils profession. Because of the very nature of the deposit, a closer look at its soil stratigraphy would be of real benefit.

The article presented in *Oregon Geology* indicated that it was a summary of a master's thesis completed in 1977. I would direct Dr. Parsons to this work for a more thorough discussion of the topic, including previous work, field methods, and data collection and analysis. I might add that the physical limits of the detailed study and reconnaissance for the project were determined largely by time limitations and by previous investigations. A literature review indicated that the unique deposit was, in fact, very limited in areal extent and that a much expanded study was not warranted.

Although information concerning total depth of the PHS in the Tualatin Mountains is limited, the data indicate a maximum thickness of 100+ ft. The thickness in the Chehalem Mountains, some 18 mi away, may be up to 10 ft. Assuming a direct relationship between distance and thickness, these values suggest a rate of decrease in total depth of about 5 ft per mile. Though admittedly simplified, this model would easily account for the absence of PHS on the Red Hills, about 5 mi further southwest.

The *Oregon Geology* article notes that the stratigraphic relationship between PHS and the Willamette Silt was determined in the Tualatin Valley. PHS near Springville Road was unconformably overlain by sediments correlated with the Willamette Silt. If the unconformity detected was indeed that of the Calapooyia surface, the upper age limit for the PHS may be pushed back from ~35,000 to >40,000 years B.P. However, I don't believe that this has a serious impact upon the concepts which I presented.

Except for minor differences in the heavy mineral suite, the mineral composition of the PHS and Willamette Silt (Irish Bend member of Balster and Parsons, 1968) is very similar, thus indicating a common provenance. However, after examining hundreds of PHS outcrops I am convinced that rare, out-sized clasts ("erratic" or "exotic" pebbles) in the silt are the result only of colluvial or alluvial contamination (sometimes forming stone lines) during or after deposition. In addition, I found that the PHS is truly devoid of *primary* depositional structures associated with fluvial or lacustrine deposits. For these, and other important reasons, which are discussed at length in my thesis, it appears very unlikely that PHS was originally waterlaid and subsequently uplifted or displaced.

March 3, 1981

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Glenn, J.L., 1965, Late Quaternary sedimentation and geologic history of the north Willamette Valley, Oregon: Corvallis, Oreg., Oregon State University doctoral dissertation, 231 p.

Parsons, R.B., 1969, Geomorphology of the Lake Oswego area, Oregon: Oregon Department of Geology and Mineral Industries, The Ore Bin, v. 31, no. 9, p. 187-192.

Theisen, A.A., and Knox, E.G., 1959, Distribution and characteristics of loessial soil parent material in northwestern Oregon: Proceedings of the Soil Science Society of America, v. 23, no. 5, p. 385-388.

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Pacific Northwest Metals and Minerals Conference to meet in April

The Pacific Northwest Metals and Mineral Conference will be held April 27-29, 1981, at the Red Lion Inn, 1000 N.E. Multnomah, Portland, Oregon. Hosts for the meeting are the Oregon chapters of the American Society for Metals; American Welding Society; American Institute of Mining, Metallurgical and Petroleum Engineers; and National Association of Corrosion Engineers.

Theme of the Monday morning keynote session will be "Minerals, Metals, and Energy in the 80's." Other sessions include gold and money, gold technical, gold mining, small mining, geology of the Northwest, regional mineral developments of the Northwest, ASM metallurgy/materials science, resource and process development, innovations in welding research, rare metals, applications of welding to engineering structures, and corrosion.

Cost of registration for the entire session, including two luncheons and Tuesday evening banquet, is $65. Single-day registration fees are: Monday, $28; Tuesday, $42; and Wednesday, $18. Student registration (sessions only) is $5.

To register, contact Patrick M. Wall, c/o Stark Steel and Supply Co., 6330 N. Basin, Portland, OR 97217; phone (503) 285-5251. For copies of the program, contact Steve O'Hare, U.S. Bureau of Mines, P.O. Box 70, Albany, OR 97321; phone (503) 967-5894. □

Geothermal meeting set for May

The Geothermal Resources Council, Washington State Energy Office, and the Oregon Department of Energy are sponsoring a geothermal meeting to be held May 19-22, 1981, at the Thunderbird Motor Inn, Jantzen Beach, in Portland. The meeting will be held in two parts: Part I—Geothermal Systems in the Cascades: Evidence from Recent Field Studies (May 19-20); and Part II—Geothermal Exploration and Development in the Cascades (May 21-22).

The purpose of this meeting is twofold: 1. To publicize geothermal energy as an existing alternative energy source in the Pacific Northwest and a response to the requirements in the Pacific Northwest Electric Power Planning and Conservation Act; and 2. To present potential developers and users of energy with information on the nature of the resource and its occurrence in the area, the results of recent field studies, an outline of the various uses of geothermal energy, and state and federal policies affecting geothermal development as well as its place in overall land use planning programs of the Cascade region.

Weather permitting, two field trips are planned in conjunction with the meeting. The first is a flight over Mount St. Helens on the morning of May 19. The second is an overnight trip to see geothermal exploration at Meagher Creek, Vancouver, B.C., on May 23 and 24.

For more information, contact Elaine Clark, Geothermal Resources Council, PO Box 98, Davis, CA 95617; phone (916) 758-2360. □

In 1980, a total of 1,443 new oil and gas fields were discovered in the United States.

—Petroleum Information Corporation

USGS publishes field trip guidebook to volcanic terranes

The U.S. Geological Survey (USGS) announces the release of Circular 838, *Guides to Some Volcanic Terranes in Washington, Idaho, Oregon, and Northern California*, guides for field trips held in conjunction with the Pacific Northwest American Geophysical Union meeting held September 1979 in Bend, Oregon.

The 189-page book contains field trip guides for (1) Columbia River basalt between Lewiston, Idaho, and Kimberly, Oregon; (2) the area between Kimberly and Bend, Oregon; (3) central High Cascades, Bend, Sisters, McKenzie Pass, and Santiam Pass, Oregon; (4) Newberry Volcano, Oregon; (5) High Lava Plains, Brothers Fault Zone to Harney Basin, Oregon; (6) Fort Rock-Christmas Valley Basin, Oregon; (7) Medicine Lake Highland, Oregon-California; (8) Captain Jack's Stronghold, Lava Beds National Monument, California; and (9) the northern and western margins of the Medicine Lake Highland.

This volume is dedicated to editor David A. Johnston, USGS volcanologist killed in the May 18, 1980, eruption of Mount St. Helens, "... in grateful remembrance of the effect that Dave's enthusiasm, diligence, and vitality had on so many of us." Co-editor Julie Donnelly-Nolan completed the editorial work left unfinished by Dave's death and was instrumental in seeing that the volume was published as a memorial to him.

USGS Circular 838 is available free of charge to the public. A limited number of copies are available, one to a customer and over the counter only, at the business office of the Oregon Department of Geology and Mineral Industries, 906 State Office Building, in Portland. Free copies may be obtained by mail from the USGS, 604 S. Pickett St., Alexandria, VA 22304. Free copies are also available over the counter at USGS Public Inquiries offices in Los Angeles, San Francisco, and Spokane. □

CORRESPONDENCE

March 2, 1981

Editor:

I read with interest the account of the naming of Oregon's southernmost glacier which appeared on page 20 of the February 1981 issue of *Oregon Geology* (v. 43, no. 2).

However, the photograph accompanying the article does not show the northeast side of Mt. Thielsen.... The photograph you ran shows the east and southeast faces, with the Cottonwood Creek drainage running off to the right and the Tiny Creek drainage running toward the bottom of the photograph....

In addition, I have written a third article on our observations of the glacier entitled "Mt. Thielsen's Glacierettes: A Five-Year Update," which was published in the 1976 Mazama *Annual* (v. 58, no. 13, p. 17-20). One additional point is that Ted Lathrop died on May 20, 1979, not May 29.

Ralph H. Nafziger
2015 S.W. Ferry Street
Albany, Oregon 97321

Our apologies to Leonard Delano for misreading the information on the back of his most excellent photograph of Mt. Thielsen.—Ed.

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COVER PHOTO

Gregory Point and Sunset Bay, southwest of Coos Bay on the Oregon coast. Steeply dipping beds belong to the lower member of the Coaledo Formation of late Eocene age. The potential for oil and gas in the Coos Bay area is the subject of a study published recently by the Oregon Department of Geology and Mineral Industries (see article in right-hand column of this page). (Photo courtesy Oregon Highway Division)

Coos Basin oil and gas study completed

Coastal and offshore areas of southwestern Oregon may have potential for the commercial production of oil and gas. This conclusion highlights a comprehensive synthesis and interpretation of a variety of oil exploration-related data just released by the Oregon Department of Geology and Mineral Industries as Oil and Gas Investigation 6: *Prospects for Oil and Gas in the Coos Basin, Western Coos, Douglas, and Lane Counties, Oregon*, by V.C. Newton, Jr.

The 74-page report and accompanying maps are the results of several years of investigation supported in part by local government, private industry, and the Office of Coastal Zone Management through the Department of Land Conservation and Development. Similar reports in the Department's oil and gas investigation series, notably those on the Mist area and on portions of Linn County, preceded recent commercial discoveries in those areas.

Major sections of the report deal with the geology of the Coos Basin and of the continental margin, with plate-tectonic, geochemical, geophysical, petrographic, and paleontological data, partly in analyses of samples and well cuttings.

Lithologic logs and foraminiferal species lists used in the preparation of Oil and Gas Investigation 6 have also been released in the Department's 81-page Open-File Report 0-80-13, *Lithologic Logs of Eleven Wells and Foraminiferal Species Lists of Four Wells in Southwestern Oregon*. The species lists, including paleobathymetric interpretations, were prepared by D.R. McKeel, Consulting Micropaleontologist. The four wells for which foraminiferal studies were made are included among the eleven wells of the lithologic report. Two of the wells are offshore wells.

Price of Oil and Gas Investigation 6 is $9.00; price of 0-80-13 is $4.00. Both may be purchased from the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. Payment must accompany orders of less than $20. □

Mailed single copies of magazine to cost more

Because postal rates have increased, the price of a mailed single issue of *Oregon Geology* has been raised from $.50 to $.75. The over-the-counter price of a single issue and subscription rates remain the same. □

CONTENTS

Oregon's coal and its economic future

by Michael E. Brownfield, Research Geologist, Oregon Department of Geology and Mineral Industries

INTRODUCTION

Coal has been mined intermittently in Oregon since the 1850's (Figure 1). Most of the coal prospects were opened to provide fuel for local consumption. The Coos Bay field is the only coal-bearing area in Oregon that has had a consistent history of commercial production; its recorded production from 1880 to 1920 was 2.38 million tons (Allen and Baldwin, 1944). Although other areas have produced coal for local consumption, mining operations have been limited because of the limited reserves and the poor quality of the coal. The total commercial production of the State up to the present has amounted to about 3 million tons. At present, there is no commercial production of coal in Oregon.

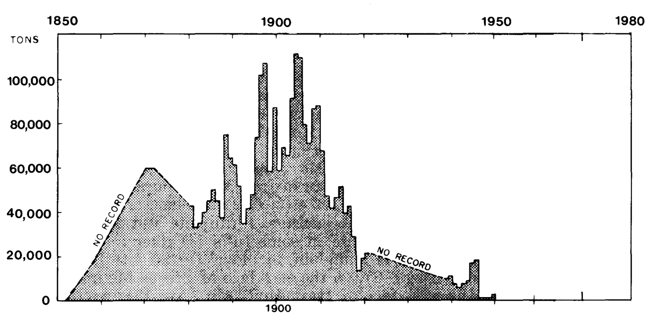


Figure 1. Coal produced in Oregon 1854 to 1980.

There are three important potential coal resource areas in Oregon: the Coos Bay field, central Coos County; the Eden Ridge field, southern Coos County; and the Flora area, northern Wallowa County (Figure 2). Other areas that have produced small tonnages of coal include the Squaw Basin and Eckley fields of southern Coos County, the Rogue River area in Jackson County, the Vernonia area of Columbia County, the Wilhoit area of Clackamas County, the Waldo Hills area of Marion County, and the Shasta Costa area of Curry County. Other Oregon counties in which thin seams of low-grade coal are known to crop out include Tillamook, Lincoln, Yamhill, Douglas, Grant, Morrow, Wheeler, and Wasco Counties.

COOS BAY COAL FIELD

The Coos Bay coal field is located in the west-central part of Coos County. It lies within a roughly elliptical structural basin measuring approximately 35 mi from north to south and 11 mi from east to west. Over 12,000 ft of sediments were deposited in the basin beginning in the early Eocene and ending in the Pleistocene (Figure 3).

About 6,000 ft of upper Eocene coal-bearing sediments of the Coaledo Formation are confined to this complex structural basin. The lower and upper Coaledo members consist of medium-bedded tuffaceous sandstones, separated by the middle Coaledo member consisting of as much as 2,500 ft of dark tuffaceous shale (Allen and Baldwin, 1944; Baldwin, 1966). The following passages are abstracted from Allen and Baldwin (1944) and refer to the coal-bearing members only.

"The coals within the upper member of the Coaledo formation are known as the upper coal group. Of these coals, the Beaver Hill bed is the most prominent. This bed lies at or near the base of the coal group; only one thin bed is known to underlie it in the Newport basin and west of Beaver Hill. Attempts to mine other beds (Henryville, Empire, Gibbs) have in most cases been unsuccessful, the beds being either too thin or too dirty. However, the Riverton or Timon bed which lies several hundred feet above the Beaver Hill has been mined for many years. The upper coal group consists of as many as six or seven coals in a stratigraphic distance of from 600 to 1,000 feet.

"The Beaver Hill bed is characterized by three benches of coal, which are about 6, 20 (top), and 30 (bottom) inches thick, although these vary considerably. The lower bench is generally bony in its lower portion. The roof is usually firm, which is not generally true of other upper coals.

"Toward the southern end of the Beaver Slough basin, the Beaver Hill bed becomes dirty, although it maintains its thickness (Panter, Lyons). Toward the north end of the basin it splits and the benches are widely separated (Englewood, Reservoir)" (p. 67).

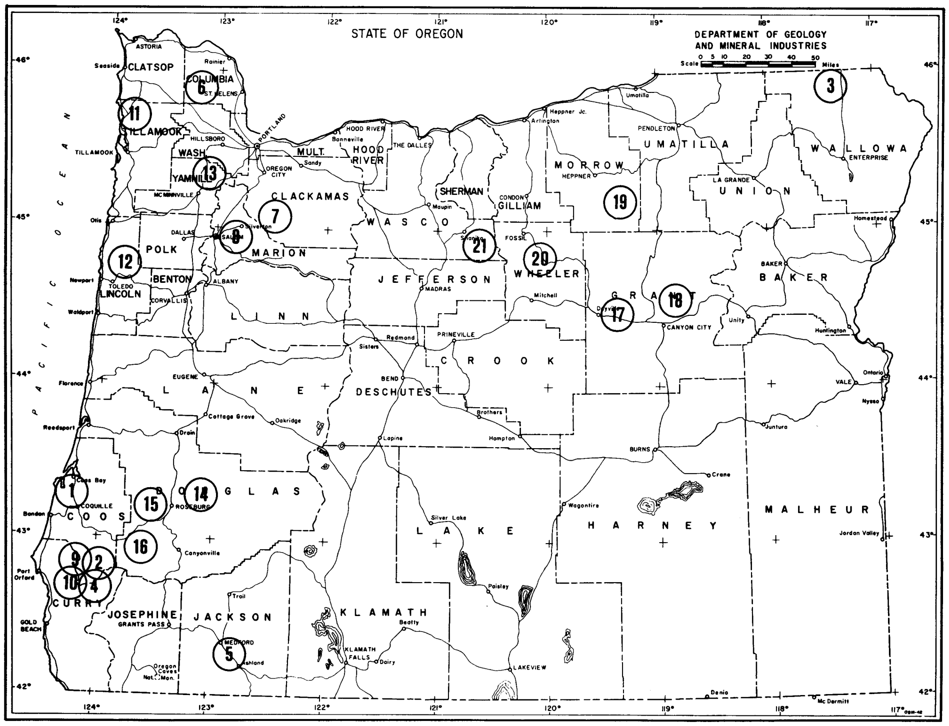
"The coals occurring within the lower Coaledo member are known as the lower coal group and lie stratigraphically far below the Beaver Hill bed of the upper group, being separated by the middle Coaledo shale and much of the lower Coaledo formation. At least seven coals are known, but only a few of these have ever been mined successfully, and these only on a limited scale. Several attempts have been made to mine these coals, especially in the Lampa Creek area....

"The coals of the lower group have numerous and thick shaly partings...and a high content of bone. Their B.t.u. content and rank, when a clean sample is analyzed, are usually higher than those of the upper coals. Most of the beds have shaly or otherwise unfavorable roof conditions. The cleavage of these coals is more likely to be platy than blocky" (p. 131).

The coals in the Coos Bay field are of subbituminous rank and have heat values ranging from 9,260 to 10,080 Btu per pound on an "as received" basis. The coals are characterized by a relatively high moisture content, a moderate percentage of ash, and a low sulfur content (Allen and Baldwin, 1944).

The Coaledo and the later Oligocene formations were compressed during the Miocene into several parallel northward-trending folds and faulted by north-trending faults and by numerous transverse faults. Although the displacement of the coal-bearing strata has not been great, the offset produced by this faulting has been the deciding factor on limiting the size of several of the mines. Because of the steepness of the dip, mining operations were forced to considerable depth, where the weight of overlying strata caused the mine floor to heave. These mining problems were contributing factors in the eventual closure of such main producers as the Beaver Hill (Figure 4) and Libby (Figure 5) Mines.

Estimates of coal resources in parts of the Coos Bay field



PRINCIPAL COAL FIELDS IN OREGON

1. Coos Bay
2. Eden Ridge
3. Flora

MINOR COAL LOCALITIES

4. Squaw Basin
5. Rogue River
6. Vernonia
7. Wilhoit
8. Waldo Hills
9. Eckley
10. Shasta Costa
11. Neahkahnie
12. Yaquina
13. Yamhill
14. Cavitt Creek
15. Lookingglass
16. Camas Valley
17. Stewart Ranch
18. Davis Creek
19. Willow Creek
20. Dry Hollow
21. Dry Creek

Figure 2. Coal occurrences in Oregon

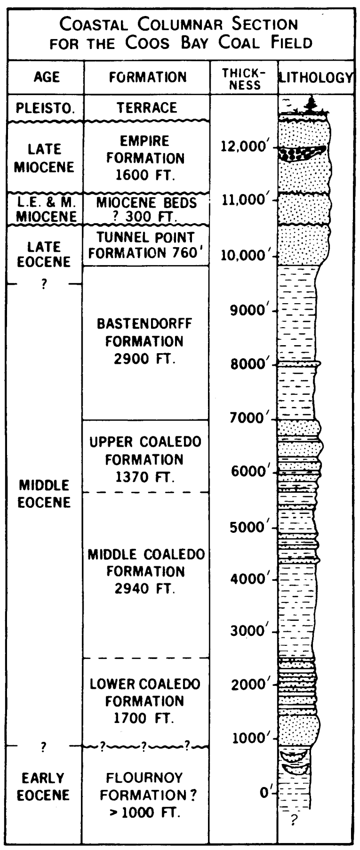


Figure 3. Coastal columnar section from the Coos Bay coal field. (Modified from Armentrout, 1980)

were made by Allen and Baldwin (1944), Duncan (1953), Toenges and others (1948), and Mason and Hughes (1975). Their estimates were based on information from extensive test drilling, outcrops, and studies of mines in the area. Mason and Hughes (1975) estimated the existing coal resources to a depth of 1,500 ft and concluded that the total resources were approximately 119.38 million tons, with about 87 million tons calculated to be in the Beaver Hill bed.

EDEN RIDGE COAL FIELD

The Eden Ridge coal field is located in southern Coos County. The South Fork of the Coquille River cuts through the south end of Eden Ridge, a prominent ridge east of Powers, Oregon. The coal field occupies an area along the divide between the Coos and Rogue Rivers, where the relief is about 3,000 ft.

The Eden Ridge coal field was first investigated by Lesher (1914). Since Lesher's initial report, other investigations by Mason and Erwin (1955), Mason (1956), and Wayland (1964) have been published.

The coal-bearing sediments found in the Eden Ridge coal field are part of the middle Eocene Tyee Formation. In addition to the graded sandstone and carbonaceous siltstone typical of the Tyee Formation to the north, the coal-bearing strata at Eden Ridge also contain conglomerate, flaggy sandstone, and graywacke. In the finer units between the massive sandstones, black shales are common. Siltstones and shales are characterized by abundant plant debris. Carbonized logs and tree stumps in place (Born, 1963), as well as the several known coal beds, indicate a swampy, nonmarine environment. A locally continuous 40-ft-thick conglomerate bed, originally described by Lesher (1914) and named informally the Blue conglomerate, consists of pebbles of altered andesite, quartzite, and slate ranging in size from one-eighth of an inch to 2 in. in diameter. Lesher (1914) mapped coal above the Blue conglomerate in the Eden Ridge field at four horizons. Drilling on

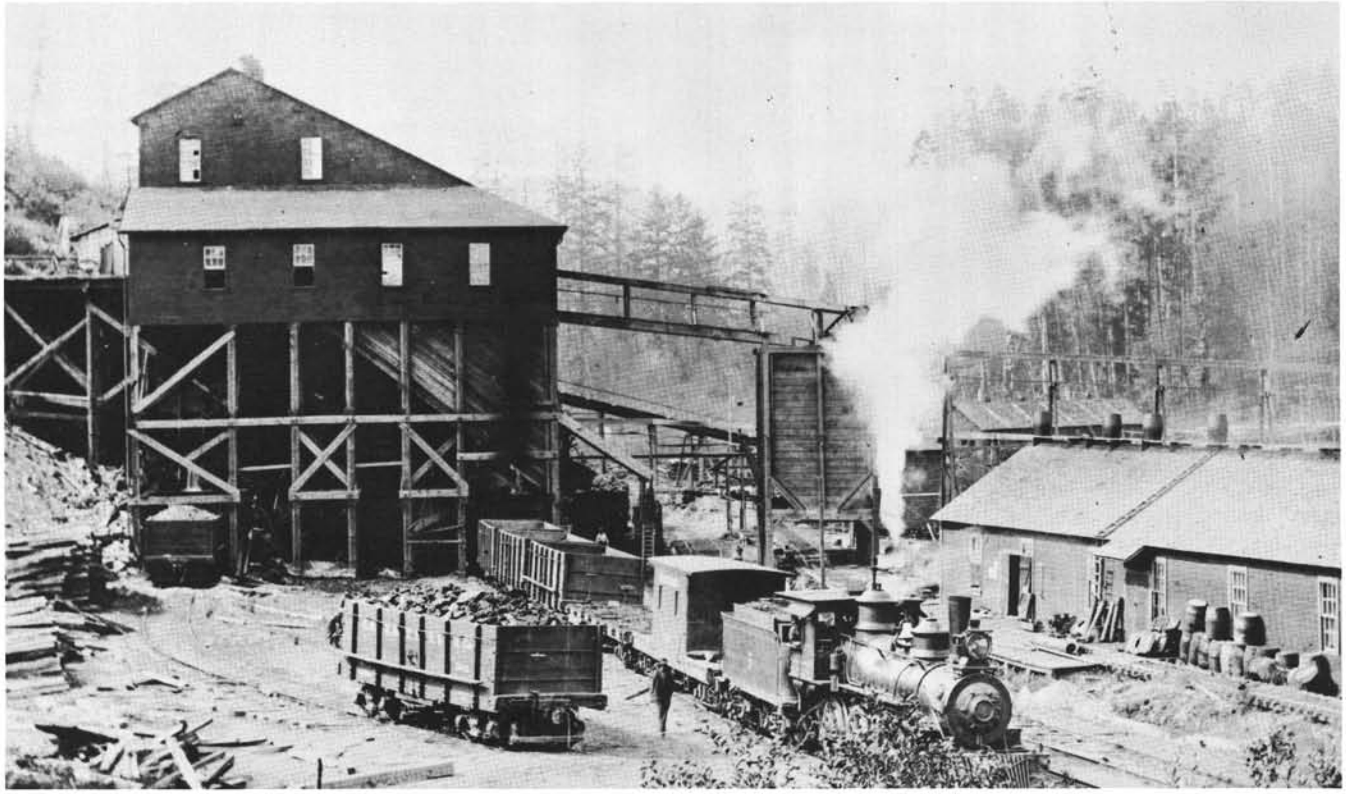
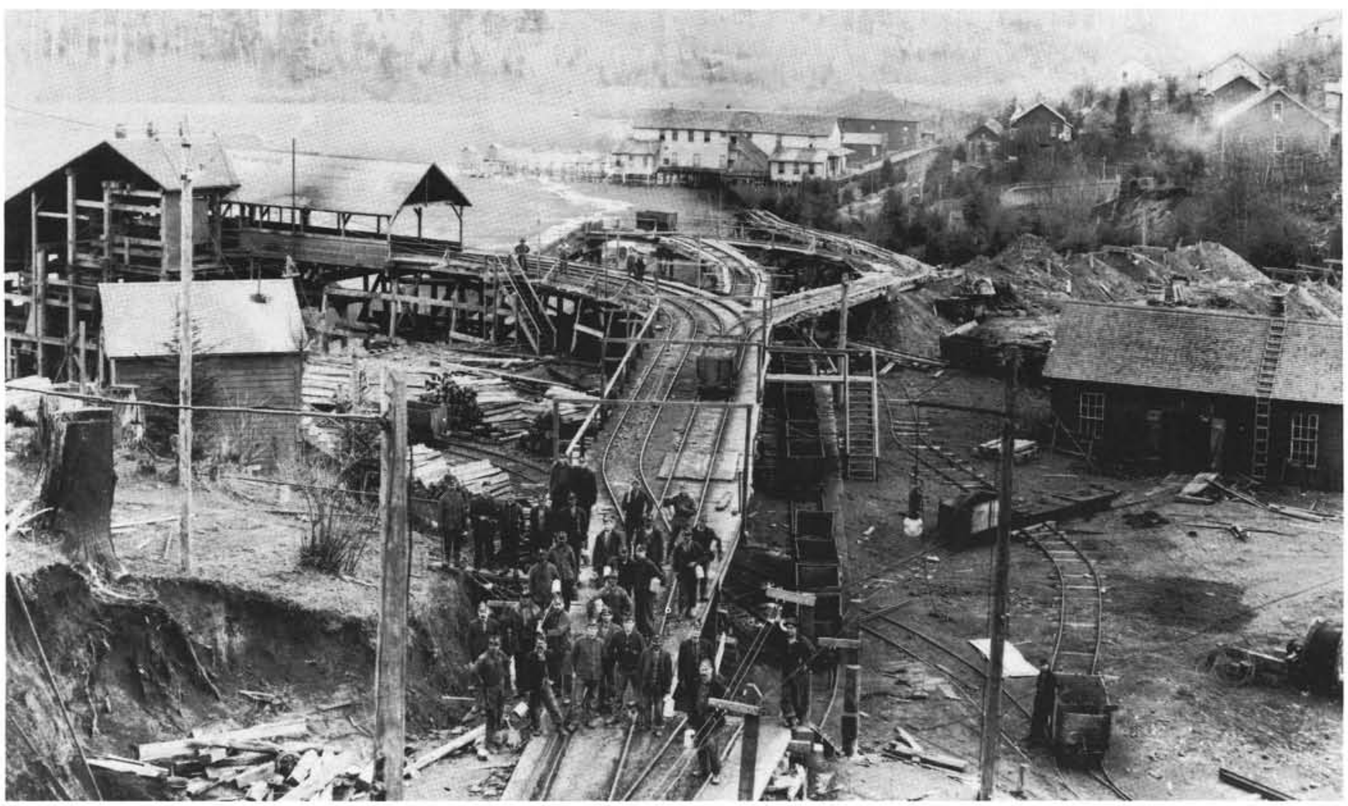


Figure 4a. Beaver Hill coal mine tipple and screening facilities, around 1895. Entrance to mine is at the left edge of photograph. Between 1903 and 1920, at least half of the total production of the Coos Bay field came from this mine, which was owned and operated by the Southern Pacific Company. (Photo courtesy Jack's Photo Service, Coos Bay)

Figure 4b. View from above the Beaver Hill screening facilities and town of Beaver Hill, on Beaver Slough. (Photo courtesy Oregon Historical Society)



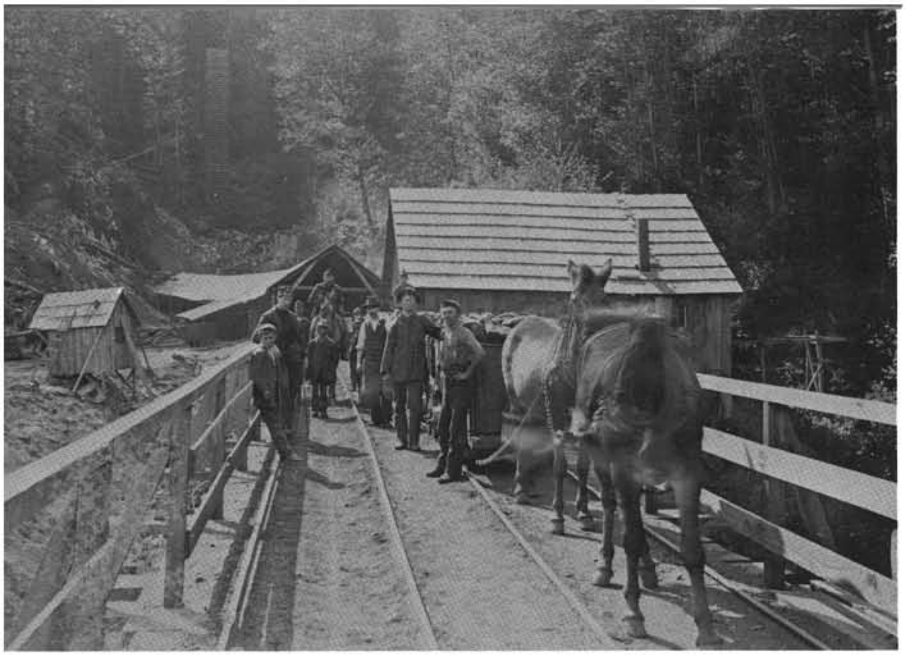
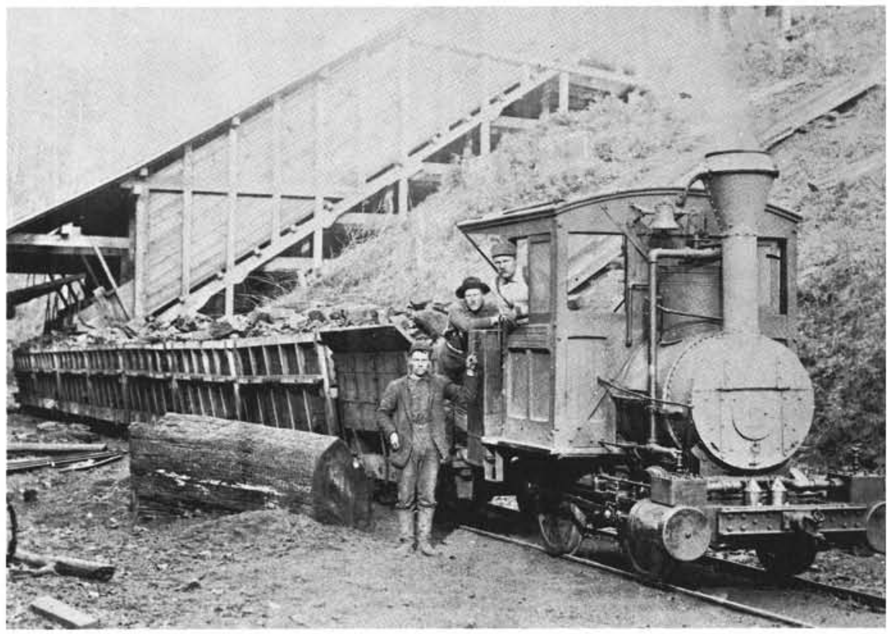


Figure 5a. A group of miners standing in front of the Libby Mine, known originally as the Newport Mine and operated by Goodall, Perkins, and Co. of San Francisco. Note small boys who also worked underground. (Photo courtesy Jack's Photo Service, Coos Bay)

Figure 5b. Screening, storage, and loading facility, located below Libby Mine portal in Boatman Gulch, around 1895. Here coal was loaded into cars and hauled by train to coal bunker on Coalbank Slough. (Photo courtesy Jack's Photo Service, Coos Bay)



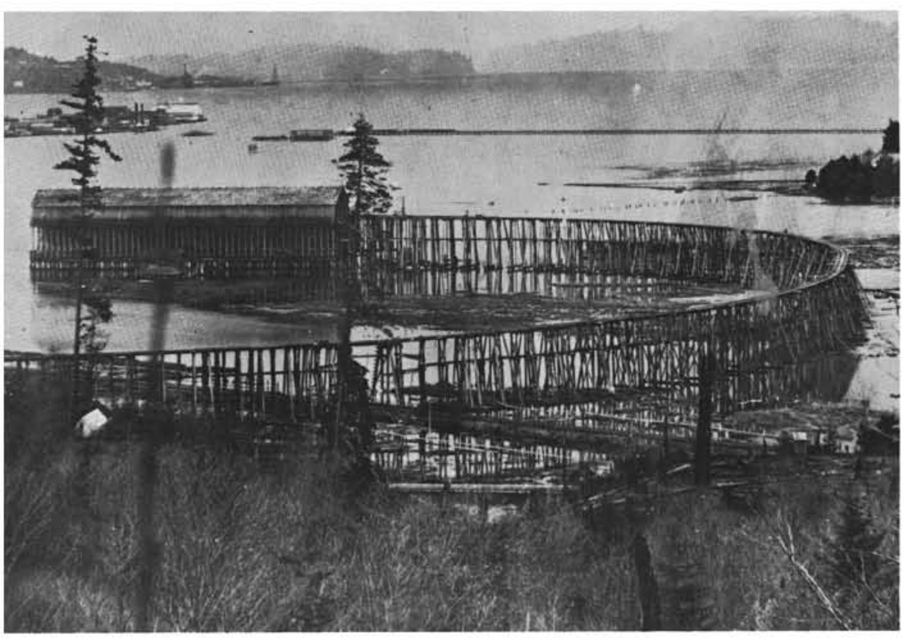


Figure 5c. Libby coal bunker on Coalbank Slough. From facilities such as these, coal was loaded onto ships and transported to the San Francisco Bay area. (Photo courtesy Jack's Photo Service, Coos Bay)

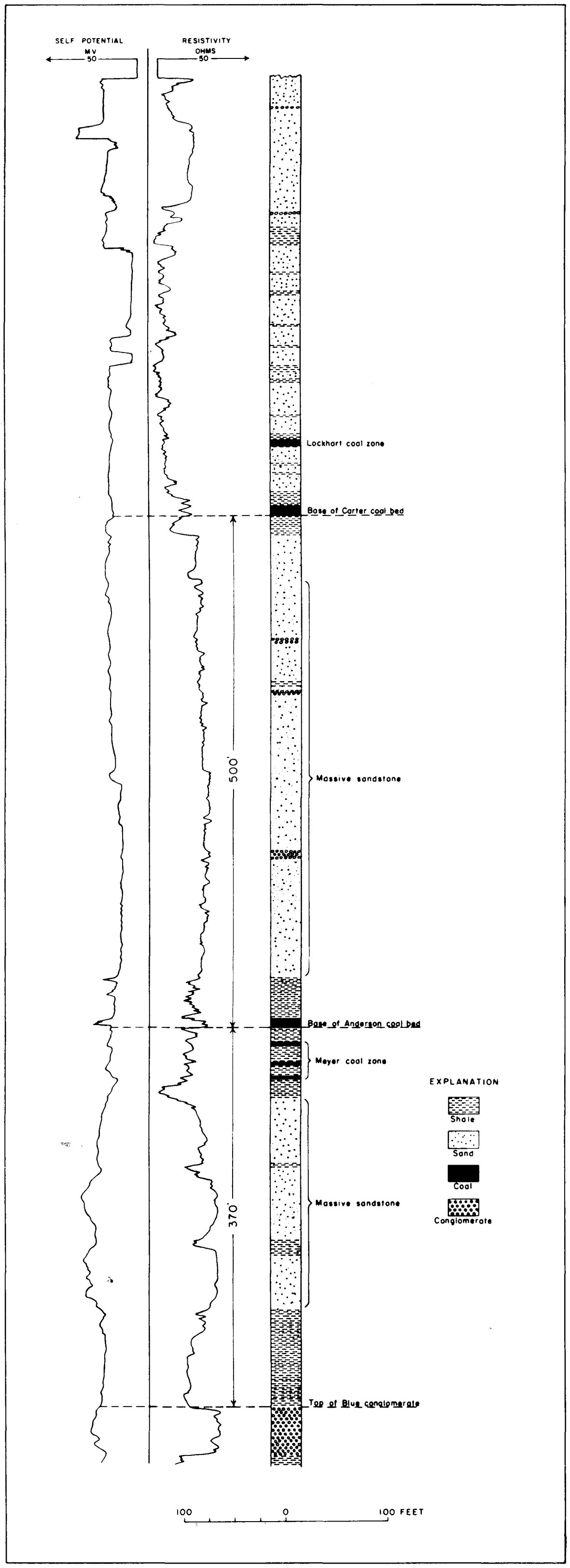


Figure 6. Composite stratigraphic section, upper portion of the Tyee Formation in the Eden Ridge coal field. Data furnished by Pacific Power and Light Company (Russell G. Wayland, 1964)

the ridge by Pacific Power and Light Company has confirmed his observations (1980, written communication). Wayland (1964) published a composite stratigraphic section and electric log (Figure 6) that corresponds well with the section described by Lesher (1914, p. 26). The Meyers coal zone is shown by the drilling to consist of three thin beds within a 50-ft interval below the base of the Anderson bed. The Anderson coal, which is 370 ft above the Blue conglomerate, and the Carter coal, 500 ft above the Anderson bed, are both finely interbedded with shale and impure coal partings. The maximum measured thickness of the Anderson bed is 9 ft, but its average is slightly over 6.5 ft. The Carter bed is more shaly and has an average thickness of 6.1 ft (Pacific Power and Light Company, 1980, written communication). The Lockhart bed, about 70 ft above the Carter bed, is mainly carbonaceous shale and thin layers of coal.

The Eden Ridge coals are subbituminous and lignitic in rank. The average heating value for the Anderson bed is 8,350 Btu per pound on an "as received" basis, and the Carter bed averages considerably less at 6,900 Btu per pound, "as received." The coals are characterized by low moisture, high ash, and low sulfur contents.

Structurally, the Eden Ridge coal field is located on a slightly asymmetrical syncline which forms an elliptical basin (Lesher, 1914). The basin is divided by three major east-west-trending faults with displacements from 80 to 600 ft (Pacific Power and Light Company, 1980, written communication). The synclinal nature of the coal basin suggests extremely wet mining conditions. This possible water problem is shown by the water conditions in old tunnels and by artesian flow from drill holes.

Pacific Power and Light Company has estimated the coal resources in the Eden Ridge field at approximately 50 million tons, with about 70 percent of the total estimated from the Anderson bed and the remainder from the underlying Carter bed (1980, written communication).

FLORA, WALLOWA COUNTY

A possible new extensive coal field has been found in the northeast corner of the State in Wallowa County, near the communities of Flora and Paradise. The region is a semiarid plateau lying at altitudes of 3,000 to 5,000 ft.

The coal-bearing sediments found near Flora are sedimentary interbeds in the Columbia River basalt and consist of thin-bedded tuffs and tuffaceous sediments composed of silicic volcanic detritus and clay minerals (Figure 7). Minor carbonaceous zones, charred logs and limb fragments, and a few interbeds of well-sorted sandstone composed of quartz, feldspar, and mica are also found. The sediments were deposited in lacustrine and fluvial environments during quiescent periods that occurred during late middle Miocene time. This sequence of continental interbeds has been named the Grouse Creek interbed by Ross (1978) for outcrops west of Troy, Oregon. Walker (1979) also mapped a sequence of sedimentary interbeds between flows in the upper Yakima Basalt Subgroup of the Columbia River Basalt Group of Swanson and others (1979). The Grouse Creek (?) sediments overlie the Umatilla flow of Wright and others (1973) and underlie the Buford flow of Walker (1973, 1979) in the Flora area.

The Flora coal is lignitic in rank and has a heating value of 7,900 Btu per pound, "as received" (Stoffel, 1981, oral communication). The lignitic coal bed is reported to have a thickness of 20 ft or more. Keith Stoffel, Washington Department of Natural Resources, reports that north of Troy, Oregon, in the State of Washington, there is a 40-ft-thick lignitic coal seam with a heating value ranging from 5,000 to

8,000 Btu per pound, "as received."

The coal-bearing sedimentary interbeds at Flora are related to a regional subsidence of the Columbia Plateau that started with the eruption of the Grande Ronde Basalt flows (14.0-16.5 million years ago) of the Columbia River Basalt Group and continued through the eruption of the Wanapum and Saddle Mountains Basalt flows, also of the Columbia River Basalt Group. Starting in early Saddle Mountains Basalt time (13.5 million years ago), quiescent periods occurred during which the sediments accumulated. Continuing deformation of the area resulted in the eruption of the overlying flows (approximately 10.5 million years ago). Most of the faulting and uplift of the Blue Mountains occurred after the end of volcanism in the area.

Because of the lack of surface and subsurface data, the coal resources for the Flora area cannot be estimated at the present time.

FACTORS INFLUENCING COAL DEVELOPMENT IN OREGON

Coal beds are mined by either surface or underground methods. Many factors enter into the problem of determining whether a coal prospect may be developed into a mine. Physical factors, mine development costs, and environmental factors all contribute to the minability and marketability of the coal deposit.

Several physical factors contribute directly to the development of the mine plan and influence the type of preparation facilities, the mine size and life, the type of transportation system, and the marketability of the coal. These factors include the character of the coal, thickness of the coal, number and thickness of partings of either clay or bony material, attitude or dip of the coal, the type and amount of faulting, the competency of the roof and floor rock, the amount of water and gas encountered, availability of power, and distance and difficulty of transportation to the nearest market.

The character of the coal includes information on its rank, friability, slacking characteristics, heat value, coking ability, and other analytical data. The rank of a coal seam describes the stage of carbonification or coalification attained by a given coal during diagenesis and metamorphism and is the basis for a classification series from lignite to anthracite. Friability, as applied to coal, is the tendency of a coal to break down in size during storage and handling while being mined or transported. Slacking is the degradation of coals during exposure to the weather, particularly when alternately wetted and dried or subjected to hot sunshine. The heat value of a coal is its caloric value expressed in British thermal units per pound (Btu per pound). The ability of a bituminous coal to form coke is its ability to fuse and form porous masses of carbon and ash which burn very slowly and create intense heat. Coke is commonly formed artificially, but natural coke is known, for example, where an igneous dike has intersected a bituminous coal seam and has converted the bordering coal to natural coke. Other important analytical data acquired during testing of a coal seam are the amounts of sulfur, moisture, volatile matter, and fixed carbon.

In underground mining, the thickness of a coal seam determines the kind of mining equipment that can be used. Thin seams require additional expense for brushing out the roof or floor of an underground mine to allow access for equipment and miners. Special, expensive equipment has been developed for underground mining of thin, flat-lying seams of coal in the eastern United States. Thick seams may require benching and costly extra support for the roof.

The occurrence of numerous partings in a coal seam raises production costs, as larger tonnages must be mined to produce a ton of finished product. Clay and bony coal partings must be removed by washing and sorting methods before the coal can be transported. Special equipment may be needed to mine the coal seam because partings may damage conventional mining equipment.

The dip of the coal seam is one of the factors that determine the minability of the prospect. In most cases today, coal seams exceeding 15° in dip cannot be mined. Steeply dipping coal beds pose a number of problems compared to flat or gently dipping coal seams. Mining steep coal beds is inefficient due to the greater effort needed to remove the coal from the mine, the effort in pumping out mine water if present, the increased effort and safety problems incurred by miners when working on steeply inclined surfaces, the lack of efficient equipment when compared to flatter slopes, and the need for greater roof and floor support as the mine is developed downdip.

Faulting within a coal prospect will strongly influence the minability of the coal seam. Even though the displacement along faults may not be great, added mining expense can be a factor. Underground mining may require inclines to follow the displaced coal seam, and damage to coal-mining equipment may occur when a fault zone is encountered. Surface-mining expenses increase when the overburden changes because of faulting.

The roof and floor conditions in underground mining have frequently determined the minability of a given coal prospect. The roof rock may require bolting or timbering to prevent caving. The floor may swell, causing added expense to remove the floor rock. Because of poor roof and floor conditions, the size of the rooms must be smaller, thereby reducing the amount of coal that may be removed from the mine.

Drainage of both underground and surface mines is an added potential expense in mining a coal seam. Large amounts of water must be controlled. Water in underground mines must be pumped out; in surface mines, the water must be controlled and prevented from entering streams and rivers.

The amount of gas encountered in underground mines is an obvious safety problem. The gas needs to be ventilated to prevent explosions and bad air.

The availability of power definitely influences the mining of a coal prospect. Without power, none of the underground and surface facilities for mining, processing, and transporting the coal could be used.

The location and type of market greatly influence the development of a coal property. Long-distance transportation of the coal to market is one of the greatest expenses in coal production. The distance to the market and the degree of difficulty in transporting the coal are determining factors in the future of any coal basin. At present, the railroads are the most common means of transporting large quantities of coal to market. The building of new rail routes is expensive and requires the development of large mines and dependable markets to justify the expense.

Modern mining is a highly mechanized and automated operation with large output coupled with large preparation facilities and high-speed transportation systems. A large capital outlay is necessary to achieve operating economies, and small companies cannot afford the capital outlay necessary to compete. A large mine operation is developed for long-term productivity and long-term delivery contracts. The small mine, on the other hand, has difficulty in finding a dependable market because of the relatively small number of tons produced.

There have been many improvements in mining technology over the past few years. Although surface mining has

EXPLANATION OF MAP UNITS

Qtg TERRACE GRAVELS (PLEISTOCENE)

Qls LANDSLIDE DEBRIS (PLEISTOCENE)

QTl LOESS (PLEISTOCENE AND PLIOCENE)

1:250,000

5 0 5 Miles

NORTH

COLUMBIA RIVER BASALT GROUP (MIOCENE)

Tba *Basalt and andesite—Includes the Buford and Wenaha flows of Walker (1973) and part of upper Yakima Basalt of Wright and others (1973)*

Tls *Lacustrine and fluviatile sedimentary rocks—Tuffaceous sediments including lignitic coal beds*

Tbf *Basalt—Includes portions of the lower, middle, and upper Yakima Basalt of Wright and others (1973)*

GEOLOGIC SYMBOLS

CONTACT—Approximately located

FAULT—Dashed where approximately located (ball and bar on downthrown side)

ANTICLINE

SYNCLINE

Figure 7. Geologic map of Flora and surrounding area, northeastern Oregon. (From Walker, 1979)

received the greatest share of attention, there have been improvements in underground mining as well. For the most part, all of these improvements have been developed for the large, relatively flat, moderately thick, near-surface coal seams which have been subjected to a minimum of faulting or folding. In contrast, few, if any, advances in mining technology have been made for mining thin, steeply dipping seams at depths greater than 1,000 ft.

Mining operations of any kind must be studied as to their effect on the various elements of the environment. Surface mining has the greatest initial effect on the environment and is addressed with sound mined-land reclamation practices. Underground mining has a lesser impact.

Before any large-scale coal-mining operation can be undertaken in Oregon, a significant amount of exploratory drilling, coal-sampling and analysis, and geologic mapping would have to be done to determine definitely the minability and marketability of the particular coal deposit. Environmental concerns dealing with the impact of coal mining would have to be addressed. Additional research and development of new mining technologies and the development of new coal markets at some future time may lead to the development of a commercial coal operation in Oregon.

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Abstract of Department paper given at OAS

The following abstract of a paper presented at the Oregon Academy of Science in February 1981 at Portland State University summarizes some of the Oregon Department of Geology and Mineral Industries' current mapping projects in northeastern Oregon.

GEOLOGY AND MINERALIZATION OF THE BOURNE AND MT. IRELAND QUADRANGLES, NORTHEASTERN OREGON, *by M.L. Ferns and H.C. Brooks, Baker Field Office, Oregon Department of Geology and Mineral Industries, 2033 First St., Baker, Oregon 97814.*

DOGAMI geologists are remapping parts of the Elkhorn Mountains of northeastern Oregon. The Bourne and Mt. Ireland quadrangles contain mostly pre-Tertiary rocks of the oceanic terrane of Brooks and Vallier. These rock units include the Elkhorn Ridge Argillite which is comprised of argillite, chert, and tuff; limestone; a metagabbro-metadiorite complex; altered ultramafic rocks; mafic to silicic volcanic rocks; and a melange terrane which contains blocks of all the aforementioned rock types. Fold features and faults generally strike easterly and dip steeply to the south. The Bald Mountain Batholith, mostly granodiorite of Late Jurassic age, intrudes the oceanic terrane. Gold-bearing quartz veins and lodes occur within and peripheral to the batholith. They generally fill high-angle fractures which cross-cut pre-batholith structures. The largest such vein, the North Pole-Columbia lode, is a composite vein comprised of silicified argillite breccia cut by several strands of quartz. The vein averages 25 ft in width and can be traced for over 4½ mi. Total production from the lode is estimated to be in excess of 370,000 oz gold and 360,000 oz silver. □

TRGS to discuss Pacific Northwest geology at September meeting

The Tobacco Root Geological Society (TRGS) will hold its Sixth Annual Field Conference and Technical Session at Idaho State University, Pocatello, Idaho, September 9-12, 1981. Papers on any aspect of northwest geology are invited for the technical session. Please submit GSA-style abstracts to address below by June 30, 1981.

An interesting field trip schedule is being planned. The proposed trips include a phosphate mine tour, Tertiary geology of the Pocatello area, tour of the ISU vertebrate collection, thrust belt field trip, volcanics of the Snake River Basin, and glacial features of the Sawtooth Mountains.

TRGS is a regional society interested in all aspects of northwest geology (Montana, Idaho, Wyoming, Oregon, and Washington). Members receive a subscription to the journal *Northwest Geology*. Send abstracts and requests for more information to Dr. William J. Fritz, Corresponding Secretary, The Tobacco Root Geological Society, Inc., c/o Amoco Production Company, Amoco Building, Denver, Colorado 80202; phone (303) 830-5032. □

ABSTRACTS

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

AEROMAGNETIC MEASUREMENTS, MAGNETIC SOURCE DEPTHS, AND THE CURIE POINT ISOTHERM IN THE VALE-OWYHEE, OREGON, GEOTHERMAL AREA, by Francis Michele Boler (M.S., Oregon State University, 1979)

An aeromagnetic survey, conducted in December 1976 and April 1977 by Oregon State University's Geophysics Group in the Vale-Owyhee, Oregon, geothermal area at the Oregon-Idaho border, provides data for analysis which yield a subsurface structural and thermal picture of the area. An overall RMS uncertainty for the survey of only 3.5 gammas resulted from using a magnetic base station to monitor the diurnal magnetic variation for removal from the survey values, and a transponder navigation system which provided horizontal data position determinations accurate to ± 15 m.

Fourier transformation of the two-dimensional aeromagnetic anomaly data provides a frequency domain representation, or spectrum, of the data which is useful for depth-to-source and Curie point isotherm depth calculations. Such source depth calculations show that the magnetic basement level of the crust, where the deepest magnetic sources are located, varies from about 1.5 km below sea level in the southern part of the area, where the terrain averages 1.2 km above sea level, to more than 4.1 km below sea level in the northeast part of the area, where the terrain averages 0.8 km above sea level. The Snake River Downwarp to the east of the area probably plays a role in the deepening of the basement level in the northeast. A prominent N. 40° W. trend in the magnetic anomalies of the northeast part of the area coincides with a major fault interpreted from previous gravity, heat flow, and ERTS photo studies. Some normal movement along this fault with a down-to-the-northeast component is implied by the depth of the magnetic sources in the northeast part of the area.

Basin and Range type tectonics may be related to the uplift of the southern part of the area relative to the north. Normal faults trending in N. 5° W. and N. 50° E. directions, interpreted from low pass filtered aeromagnetic data (retaining only wavelengths longer than 12 km), indicate that Basin and Range structures extend deeper than the uppermost layers of the crust.

A Curie point isotherm depth of 11 ± 3 km below sea level is implied by calculations of the depth to the bottom of sources based on the spectrum of data from the northeast part of the area. Spectra from the remainder of the Vale-Owyhee data do not yield source bottom depths, perhaps because (1) the Curie isotherm depth is too deep to have an influence on the low-frequency part of the spectrum, or (2) extensive basaltic magnetic sources occur nearly everywhere in the area except the northeast and influence the low-frequency part of the spectrum, masking the low-frequency effects of source bottoms. For the Curie point isotherm depth in the northeast part of the area, a temperature close to 580°C (the Curie point of magnetite) is reasonable because it results in thermal gradients of 45°C km^{-1} and surface heat flow values of 90-110 mW m^{-2}, which are consistent with those measured in this area.

Mean source depth calculations show sources within 1 km of sea level occurring throughout the area. With probable thermal gradients greater than 50°C km^{-1} in some areas, economically valuable geothermal waters may be found in basaltic sources at 2 km below the surface.

GEOLOGY AND MINERALIZATION OF THE NORTH SANTIAM MINING DISTRICT, MARION COUNTY, OREGON, by James Peter Olson (M.S., Oregon State University, 1979)

The North Santiam Mining District is located approximately 50 km east of Salem in the Western Cascade Subprovince of Oregon. Although the district has produced only $10,000 in metals and all mines are now presently dormant, the presence of widespread hydrothermal alteration and mineralization of a type associated with many porphyry copper-molybdenum deposits now renders this area above average in exploration significance.

Bedrock in the district consists of flow and pyroclastic volcanics of the Miocene Sardine Formation that have been intruded by dikes and plugs of diorite, quartz diorite, quartz monzodiorite, and granodiorite. The volcanic rocks in the center of the district were domed upward during the emplacement of these intrusions. An alkali-lime index of 60.5 for these plutonic rocks indicates they are representative of a highly calcic calc-alkalic sequence of magmatism. In addition, their distribution on AFM and NKC diagrams is atypical compared with normal calc-alkalic trends. These plutonic rocks are deficient in K_2O and potassium feldspar relative to average rocks of similar modal composition, and they are chemically and mineralogically similar to plutons associated with porphyry-type metallization in island arc environments.

Hydrothermal alteration and mineralization were closely associated in time and space with the emplacement of the youngest intrusions of granodiorite. Metallization consists of a central area of disseminated chalcopyrite and minor bornite that is surrounded by a zoned system of sulfide-bearing veins. The location and orientation of these veins was controlled by pre-existing northwest-trending fault and fracture zones. Chalcopyrite, the dominant sulfide near the center, grades laterally outward into assemblages dominated by pyrite and then by sphalerite and galena. A central zone of potassium silicate alteration is coincident with the area of disseminated mineralization. This zone, in turn, grades laterally outward into alteration zones characterized by phyllic and then propylitic assemblages. At least six tourmaline-bearing breccia pipes, interpreted to have formed by collapse into solution voids, were developed concurrently with mineralization and alteration.

ANALYSIS OF AEROMAGNETIC MEASUREMENTS FROM THE CENTRAL OREGON CASCADES, by Gerald George Connard (M.S., Oregon State University, 1980)

To assist in the assessment of potential geothermal resources, the Geophysics Group at Oregon State University conducted an aeromagnetic survey of the Central Oregon Cascades from 43°00' to 44°15'N and 121°00' to 122°30'W. This area includes three major centers of Holocene silicic volcanism and extends from the Basin and Range province in the east to the transition zone between the Western and High Cascades mountain ranges in the west. The aeromagnetic data were obtained using a high-quality transponder navigation system to accurately locate the position of each measurement and a magnetic base station to monitor the diurnal magnetic variation for removal from the survey values. These survey techniques yielded 60,000 data points with an RMS uncertainty of only 4.2 gammas.

Fourier transformation of the two-dimensional aeromagnetic anomaly data provides a frequency domain representation, or spectrum, of the data which is useful for depths-to-source and Curie point isotherm depth calculations. The frequency domain representation also facilitates low-pass filtering of the magnetic anomaly data to enhance regional trends. When wavelengths shorter than 15 km are suppressed, the resulting map shows a number of northwest-southeast trends in the anomalies, particularly in the southeast portion of the area. Suppressing the wavelengths shorter than 25 km reveals a N. 25° E. trend along the eastern side of the High Cascades which is obscured by the northwest-southeast trends prominent in the unfiltered anomaly map.

The magnetic source depth calculations show that the depth of the magnetic basement in the survey area varies from as deep as 6 km below sea level in the northwest portion of the area, where the terrain averages 1.1 km above sea level, to sea level in the southern half of the area, where the terrain averages 1.5 km above sea level.

Only four of nine subdivisions of the study area yield estimates of the lower boundaries of the crustal magnetized layer which relate to the Curie point isotherm depths. Spectra from the other five subdivisions do not produce source bottom depths, possibly because the Curie point isotherm is too deep to have an influence on the low-frequency part of the spectrum, or because sources with large horizontal dimensions may mask the low-frequency effects of source bottoms. The calculations show an elongate zone of elevated Curie point isotherm depths extending from the Crater Lake area to Bend, Oregon, and averaging 9 to 12 km below sea level. Assuming a Curie temperature of 580°C (the Curie point of magnetite), these shallow Curie depths predict temperature gradients greater than 50°C/km and surface heat-flow values greater than 100 mW/m^2. The limited heat-flow data available in the area support these conclusions. □

Book review

by Ralph S. Mason, former State Geologist

The Making of Oregon by Samuel N. and Emily F. Dicken (Oregon Historical Society, 1979, 208 p., paperback $12.95).

Two centuries of Oregon geography are deftly ensnared between the covers of this most informative and handsomely designed book. The Dickens have devoted 30 years of bushwhacking about the State in their search for data and understanding of the ways in which geography has shaped the destiny of the region.

Subtitled "*A Study in Historical Geography*," the volume is much more than a compendium of place names and much-repeated data. Rather, this volume explores and assesses the cultural, ethnic, economic, and industrial impacts on the State and the ways each of them, in turn, was conditioned by the region's geography.

Early on, the authors provide the reader with an overview of the entire State by taking him on an aerial tour of Oregon in which the great diversity of geographic forms is displayed by a stunning series of photographs. Even dyed-in-the-wool Oregonians will enjoy this grand tour which reaches from the coastal scenery through the High Cascades, the vast lava plains of eastern Oregon, the Blue Mountains, the Owyhee Uplands, and the Basin and Range province where flowing streams never reach the sea. This chapter ties it all together and is reason enough to have the volume on your reference shelf.

In addition to the discussion of the attractive geographic features of Oregon, the book also includes a great deal of information on the development of the State, the early-day patterns, and the shifts as social and economic pressures waxed and waned.

Transportation is vital to a region's growth, and the authors devote considerable attention to the influences of seaports, rivers, wagon roads, railroads, and modern highways on the location of growth centers. The justly famous Oregon Trail was only one of many similar routes, or variations of routes, used in the first half of the 1800's by western-moving settlers. Additional roads were opened up in response to, first, the discovery of gold in California, and, soon after, discoveries of the yellow metal in the streams of southwestern and eastern Oregon.

The Columbia, Snake, Willamette, and other rivers at one time resounded to steamboat whistles, and a network of railroads proliferated out into the rapidly developing portions of the State. Numerous historic photographs illustrate these activities as well as many of the other subjects covered in this carefully crafted work.

One can only await with considerable anticipation the appearance of the Dickens' companion volume, "*Oregon Divided, A Regional Geography*," which should be available by the end of June. □

USGS study shows nation's gas resources up, oil steady

A recently completed study by the U.S. Geological Survey (USGS) shows an increase in the mean estimate of the nation's undiscovered natural gas resources, while the mean estimate for oil resources remains the same as the last study in 1975.

USGS Open-File Report 81-192, summarizing the results of a sixteen-month investigation, sets mean estimates for undiscovered recoverable conventional petroleum resources at 594 trillion cu ft of gas and 83 billion barrels of oil. This compares with the mean estimates of the 1975 USGS study of 484 trillion cu ft of gas and 82 billion barrels of oil.

In the 1975 study, the offshore areas were assessed out to 200-m water depth. The 1980 study includes offshore provinces on the U.S. continental slopes out to 2,500 m water depth, thereby increasing the offshore areas assessed for the 1980 study by an additional 400,000 sq mi. The deeper water areas were included in the new assessment because current offshore technology has made these areas more accessible to possible development.

The undiscovered recoverable conventional oil resource estimates are provided again by the USGS at the 95 and 5 percent probability levels and are estimated to range from at least 64 billion barrels on the low side to more than 105 billion barrels of oil on the high side. The undiscovered recoverable conventional gas resources at the 95 and 5 percent probabilities range from at least 475 trillion cu ft to more than 739 trillion cu ft. This compares to the 1975 estimates of at least 50 to more than 127 billion barrels of oil, and a resource estimate for gas of at least 322 to more than 655 trillion cu ft.

Compared to the 1975 estimates, the 1980 USGS estimates show no significant change in the mean estimate for undiscovered oil resources and about a 22 percent increase in the mean estimate for undiscovered gas resources.

New information for some provinces resulted in an increase in the estimates of the regional petroleum potential; in other cases it resulted in a reduction of the resource estimates. For example, drilling in the Rocky Mountain Overthrust Belt of the Western United States has revealed a larger potential for both oil and gas than was projected in the 1975 estimates. This is also true for probable gas potential in the deeper waters offshore for the Atlantic East Coast, the deeper Gulf of Mexico, and the offshore North Slope of Alaska on the Beaufort Sea Shelf. On the other hand, results of exploratory drilling in the Gulf of Alaska, the offshore southern California Borderland, and eastern Gulf of Mexico have been disappointing to date, and geologic information obtained from these provinces indicates a reduced petroleum potential compared to the 1975 studies.

An 18-page report summarizing the results of the revised estimates, entitled "Estimates of Undiscovered Recoverable Resources of Conventionally Producible Oil and Gas in the United States, A Summary," has been released for public purchase and inspection as USGS Open-File Report 81-192. The report includes tables and maps describing the broad regional appraisals.

Copies of the summary report may be purchased from the Open-File Services Section, Branch of Distribution, USGS, P.O. Box 25425, Federal Center, Denver, Colo. 80225. Prices are $2.25 for each paper copy and $3.50 for each microfiche copy. Orders must specify the open-file report identification number and include check or money order payable to the U.S. Geological Survey. □

Gravity and aeromagnetic maps of northern and southern portions of Oregon Cascade Range now available

Geophysical maps of the entire Oregon portion of the Cascade Mountain Range are now available through the Oregon Department of Geology and Mineral Industries (DOGAMI). DOGAMI has just released three sets of such maps in its Geological Map Series: GMS-15 (gravity), covering the northern portion of the Cascades from the Washington state line to about Redmond, and GMS-16 (gravity) and GMS-17 (aeromagnetic), covering the southern portion from about Crater Lake to the California state line. The area in between, the central portion of the Cascade Range, is already covered by maps published by DOGAMI in 1978 as GMS-8 and GMS-9.

Studies of the magnetism and gravity of the earth's crust yield basic information about density, structure, faults, and temperatures, which is used in assessing geothermal potential, mineralization, and basic geology. The new maps are compilations of new and previously existing geophysical data and were prepared by the Geophysics Group of the Oregon State University School of Oceanography.

Titles and prices of the new maps (scale 1:250,000) are listed below. The maps are available at the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. Payment must accompany orders for less than $20.

GMS-15 (2 maps): *Free-air Gravity Anomaly Map and Complete Bouguer Gravity Anomaly Map, Cascade Mountain Range, Northern Oregon*. Price: $3.00.

GMS-16 (2 maps): *Free-air Gravity Anomaly Map and Complete Bouguer Gravity Anomaly Map, Cascade Mountain Range, Southern Oregon*. Price: $3.00.

GMS-17 (1 map): *Total-field Aeromagnetic Anomaly Map, Cascade Mountain Range, Southern Oregon*. Price: $3.00. □

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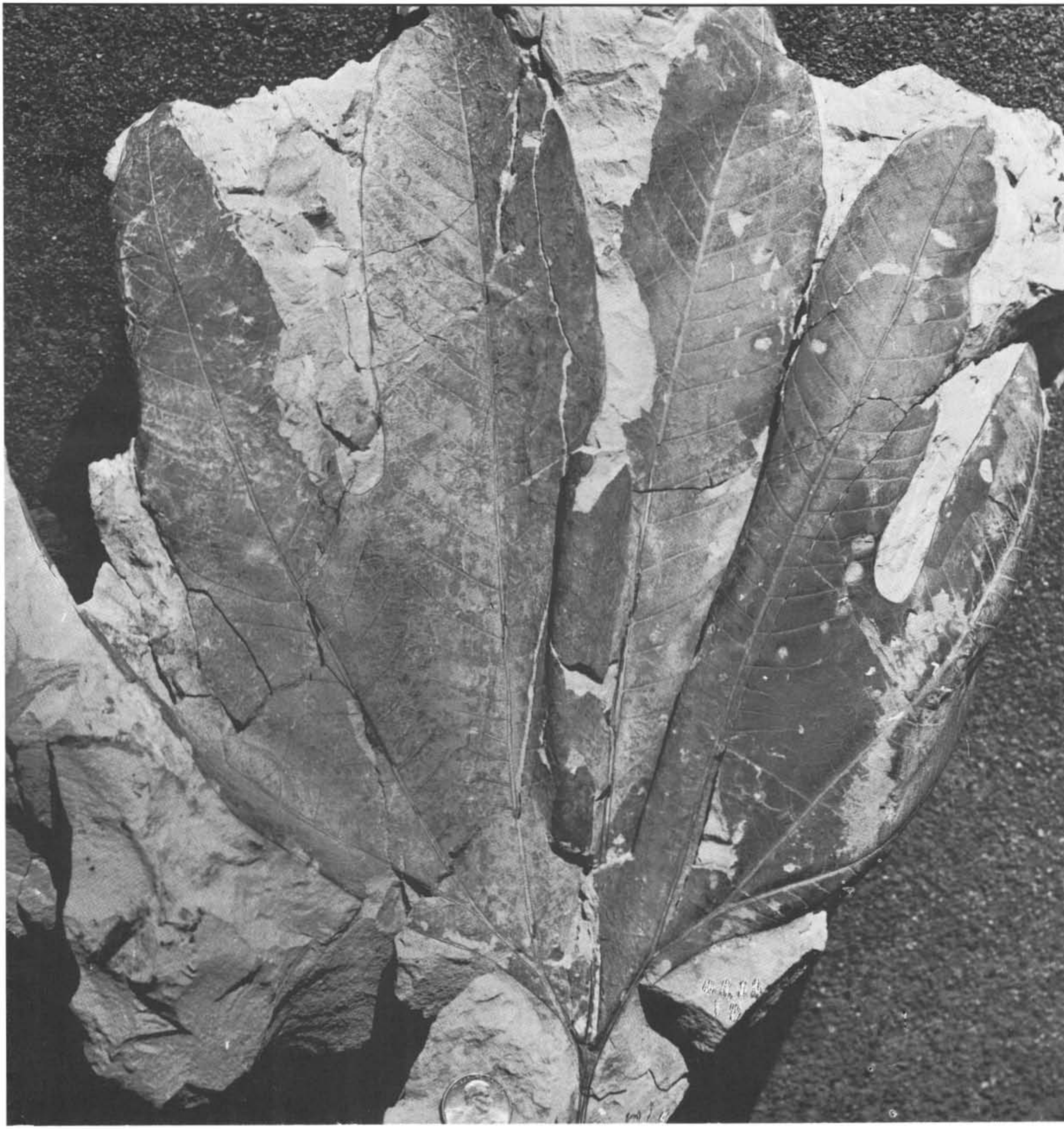

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COVER PHOTO

Leaf impression of the "Clarno Sycamore" (*Platanus* sp.), a plant common in the Eocene Clarno Formation of Oregon. This specimen, measuring 14 in., was collected by Scott Blanchard from the Cherry Creek locality. Primary veins retouched. Related article begins on next page.

Open-file reports assess geothermal resources of areas in central and eastern Oregon

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the release of five new open-file reports presenting raw and interpreted data that are the results of its U.S. Department of Energy/State of Oregon-funded low-temperature geothermal-resource studies in central and eastern Oregon. The reports contain raw and interpreted geothermal-gradient data, radiometric ages of selected rocks, chemical analyses of spring and well water, calculated minimum reservoir temperatures, extensive bibliographies, and a variety of geological and geophysical maps.

Open-File Report 0-80-4, *Preliminary Geology and Geothermal Resource Potential of the Craig Mountain-Cove Area, Oregon,* presents geothermal data for the part of the Grande Ronde River basin that surrounds La Grande, Union, and Cove in eastern Oregon. Included in the 68-page text is a generalized geologic map of the La Grande area; accompanying the text is a two-color preliminary geothermal resource map (scale 1:250,000) of the study area. Price of Open-File Report 0-80-4 is $5.00.

Open-File Report 0-80-5, *Preliminary Geology and Geothermal Resource Potential of the Western Snake River Plain, Oregon,* contains geothermal data from the western portion of the Snake River Plain, including the eastern Oregon communities of Vale and Ontario. Included in the 114-page text are three audio-magnetotelluric resistivity maps (27, 14, and 7.5 hertz) of the area; accompanying the text are two two-color generalized geologic maps and a one-color total field aeromagnetic anomaly map (scale 1:62,500) and a two-color photo-lineament and complete Bouguer gravity anomaly map (scale 1:250,000)—all of the western Snake River Plain. Open-File Report 0-80-5 sells for $10.00.

The Powell Buttes area, near Bend, Prineville, and Redmond in central Oregon, is the subject of Open-File Report 0-80-8, *Preliminary Geology and Geothermal Resource Potential of the Powell Buttes Area, Oregon.* Included in the text are photo-lineament, isogradient, complete Bouguer gravity anomaly, residual gravity anomaly, and total aeromagnetic anomaly maps of the area. Accompanying the text is a two-color geologic map (scale 1:62,500) of the Powell Buttes area. Open-File Report 0-80-8 sells for $5.00.

Open-File Report 0-80-9, *Preliminary Geology and Geothermal Resource Potential of the Lakeview Area, Oregon,* presents data from the area surrounding Lakeview in southernmost central Oregon. Included in the 108-page text are photo-lineament and total field aeromagnetic anomaly maps of the area. Accompanying the text are a one-color gravity anomaly map and a two-color generalized geologic map (scale 1:62,500) of the Lakeview area. Open-File Report 0-80-9 costs $7.00. *(Continued, page 86)*

CONTENTS

Fossil plants of the Eocene Clarno Nut Beds

by Steven R. Manchester, Paleobotany Laboratory, Indiana University, Bloomington, Indiana 47405, and Earth Science Laboratory, Oregon Museum of Science and Industry, 4015 S.W. Canyon Road, Portland, Oregon 97221

INTRODUCTION

Visitors to the Clarno Unit of John Day Fossil Beds National Monument (Figure 1) in north-central Oregon are likely to be most impressed by the present-day landscape and vegetation. Craggy rocks spotted with clumps of grass, sagebrush, and occasional juniper trees provide a rather stark setting for picnic tables. However, fossils from these same rocks show that a very different environment prevailed in the vicinity some 48 million years ago. Eocene fossils in the Clarno Formation include fan palms, cycads, magnolias, grapes, and a diversity of other plants, many of which are suggestive of a tropical rain forest.

The Clarno Formation is a sequence of volcanic flows and intrusions, mudflows, and tuffs sandwiched between marine Cretaceous sediments and the late Oligocene to Miocene John Day Formation. The age of the Clarno Formation, based upon potassium-argon radiometric dates (Enlows and Parker, 1972), ranges from Eocene to early Oligocene. Although numerous fossil plant localities are known in the Clarno Formation (Hergert, 1961), few have been studied in rigorous detail.

A large assemblage of middle Eocene plants occurs in the type area of the Clarno Formation, just west of Camp Hancock (Figure 1), on the northern border of John Day Fossil Beds National Monument. The site is called the "Nut Beds" because of the fossil fruits and seeds ("nuts") which occur there. A popular account of the petrified fruiting structures is given by Bones (1979). The Nut Beds is an unusual fossil locality because several kinds of plant parts, including fruits, seeds, woods, leaves, flowers, and pollen, are preserved there. As a result, the locality has become the focus of an intensive program of paleobotanical research (Scott, 1954, 1956; Scott and Barghoorn, 1956; Scott and others, 1962; Manchester, 1977, 1979, 1980a).

The Oregon Museum of Science and Industry (OMSI) has sponsored field research at the Nut Beds locality in cooperation with the National Park Service since 1976. Recent excavations have yielded exciting new material including a large collection of fossil leaves. The identification of these remains is an ongoing process. This paper is a brief introduction to the flora based on previous publications and recent research.

GEOLOGY AND AGE

The Nut Beds deposit (Figures 2 and 3) is comprised of tuffaceous siltstones, sandstones, and conglomerates which appear to represent stream channel and levee sedimentation. The deposit crops out in a limited area of less than 0.5 km^2 and is approximately 10 m thick. Figure 4 is a generalized stratigraphic column for the Nut Beds, based on measurements from the central face of the exposure. The sequence grades from alternating layers of siltstone and sandstone near the base

Figure 1. Geologic map of the Clarno area. The Nut Beds deposit is located adjacent to Camp Hancock on the northern border of the National Monument. (Modified from Baldwin, 1976)

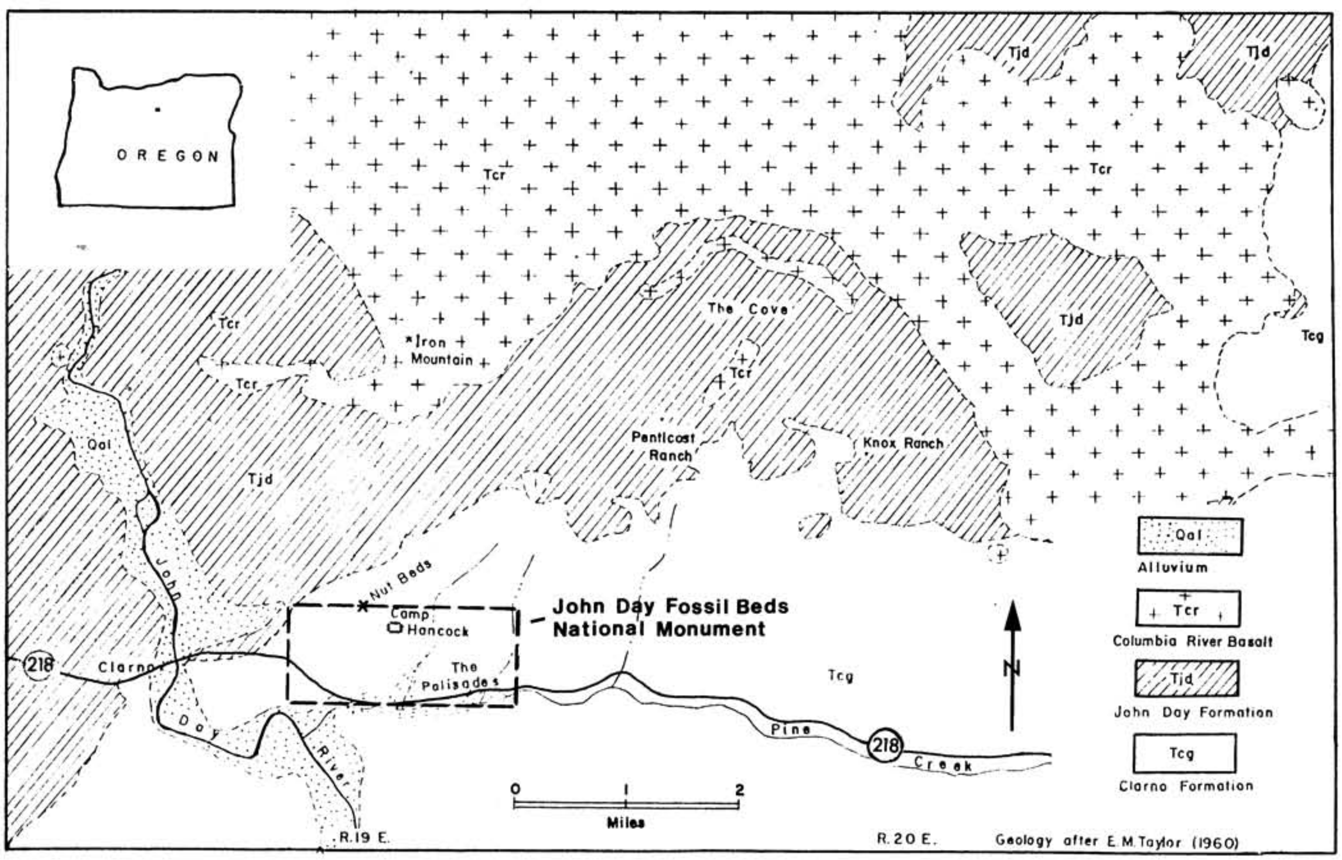


Figure 2. Northwesterly view of the Nut Beds. The deposit crops out in the faces labeled 1 through 4.

Figure 3. Profile view of Face 3 in the Nut Beds. Students are excavating fossil leaves from the basal siltstones.

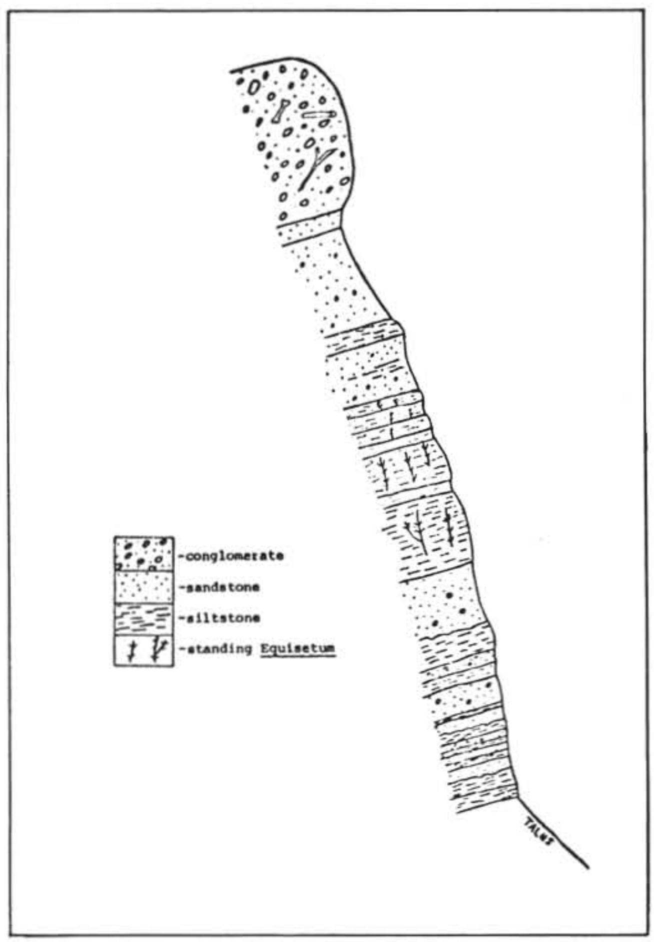


Figure 4. Generalized stratigraphic column for the Nut Beds based on measurements from Face 3. Section measures 10 m in thickness.

to coarse sandstone and conglomerate at the top. The fine-grained sediments of the basal portion contain rooted horsetails and ferns, indicating shallow-water conditions and relatively rapid burial. The upper conglomerates, which contain disarticulated vertebrate bones and waterworn woods, appear to represent stream-channel deposition. Plant remains are found throughout the horizontal and vertical extent of the exposure.

A potassium-argon date of 34.0 million years based on tuff from the Nut Beds vicinity was reported by Evernden and James (1964). This date is questionable, however, because the tuffs of the Nut Beds are highly altered, and it is unlikely that even a freshly broken sample would be suitable for accurate dating. Fossil mammal correlations suggest that the Nut Beds strata are middle Eocene, or about 48 million years old (Stirton, 1944; Hanson, 1973). Based on intensive field work in the Camp Hancock area, C. B. Hanson (1980, personal communication) suggests that the Nut Beds represent a portion of the lower Clarno Formation which was uplifted by folding prior to deposition of the Palisades mudflows and the upper Clarno tuffs.

FOSSIL LEAVES

Research in progress on the Clarno Nut Beds flora includes an intensive investigation of leaf remains. Although leaf impressions are abundant in the Nut Beds, they have received little attention in the literature. Exceptionally well-preserved specimens, some even retaining cuticle, occur in a few siltstone strata at the base of the section (Figure 3). Unfortunately, the strata are heavily fractured, making it virtually impossible to remove a leaf fossil in a single slab of rock. As each fragment is removed from the layer, its position must be marked so that adjoining parts of the same fossil may be glued together. Thus, the removal of leaves is a delicate and time-consuming operation. However, with the help of student teams, about 80 genera have been recovered since 1974. A few of the identified specimens are shown in Figures 5 to 11.

FLORAL COMPOSITION

At least 140 different genera are represented in present collections from the Nut Beds. This conservative estimate includes 100 genera of fruiting structures, 80 genera of leaves, and 40 genera of woods which are distinguishable in present collections of the Smithsonian Institution (T. J. Bones collection) and OMSI. Preliminary palynological work has also yielded several genera of pollen and spores. At this point in study, it has been possible to identify 49 taxa belonging to modern families or genera with a high level of certainty. These identifications are listed in Table 1.

Identification of the Nut Beds fossils is based upon rigorous comparisons with modern plants. When a fossil is found to exhibit a suite of characteristics diagnostic of a particular modern taxon, it may be assigned to that family or genus. For example, fossil acorns from the Nut Beds (Bones, 1979) are sufficiently distinctive to justify their identification with the modern genus *Quercus.* Sometimes a particular fossil may be matched equally well by more than one modern genus. In such cases, the fossil may be assigned to a special organ genus. For example, the organ genus *Anonaspermum* (Reid and Chandler, 1933) is used for fossil seeds of the Anonaceae because it is difficult to distinguish modern genera of the family based on seeds. In addition, some of the fossils clearly represent extinct genera for which new names must be formed. For example, the genus *Chattawaya* was erected to accommodate an extinct wood of the Sterculiaceae from the Nut Beds (Manchester, 1980a). Because of both the large number of modern plants with which comparisons must be made and difficulties in determining affinities of extinct forms, a large proportion of the Nut Beds taxa remain unidentified. Therefore, the floral list given in Table 1 excludes a large number of taxa whose affinities are as yet unknown.

Horsetails and ferns are fairly common throughout the Clarno Formation. *Equisetum clarnoi* (Brown, 1975) is especially abundant in the Nut Beds. The ferns *Dennstaedtiopsis aerenchymata* and *Acrostichum preaureum* have been recognized from silicified petioles. These species were reported earlier from another Clarno locality (Arnold and Daugherty, 1963, 1964). Two additional fern genera as yet unidentified are represented by leaf imprints in the Nut Beds.

Several frond portions similar to the modern cycad genus *Dioon* have been recovered from the Nut Beds (Figure 5). These represent the same species reported by Chaney (1937) from the Palisades mudflows. Other gymnosperms present in the assemblage include *Ginkgo,* known from a single wood sample (Scott and others, 1962) and a few leaf impressions (Figure 6), *Pinus* (pine), represented by wood and pollen, and a taxodiaceous wood, possibly *Sequoia* or *Metasequoia.*

The bulk of the flora is comprised of angiosperms, or flowering plants. The most abundant remains in this category include members of the following families: Palmae (palm family, Figure 7), Juglandaceae (walnut family, Figure 8), Menispermaceae (moonseed family, Figure 10), Lauraceae (avocado family), Sabiaceae (*Meliosma* family, Figure 11) and Platanaceae (sycamore family).

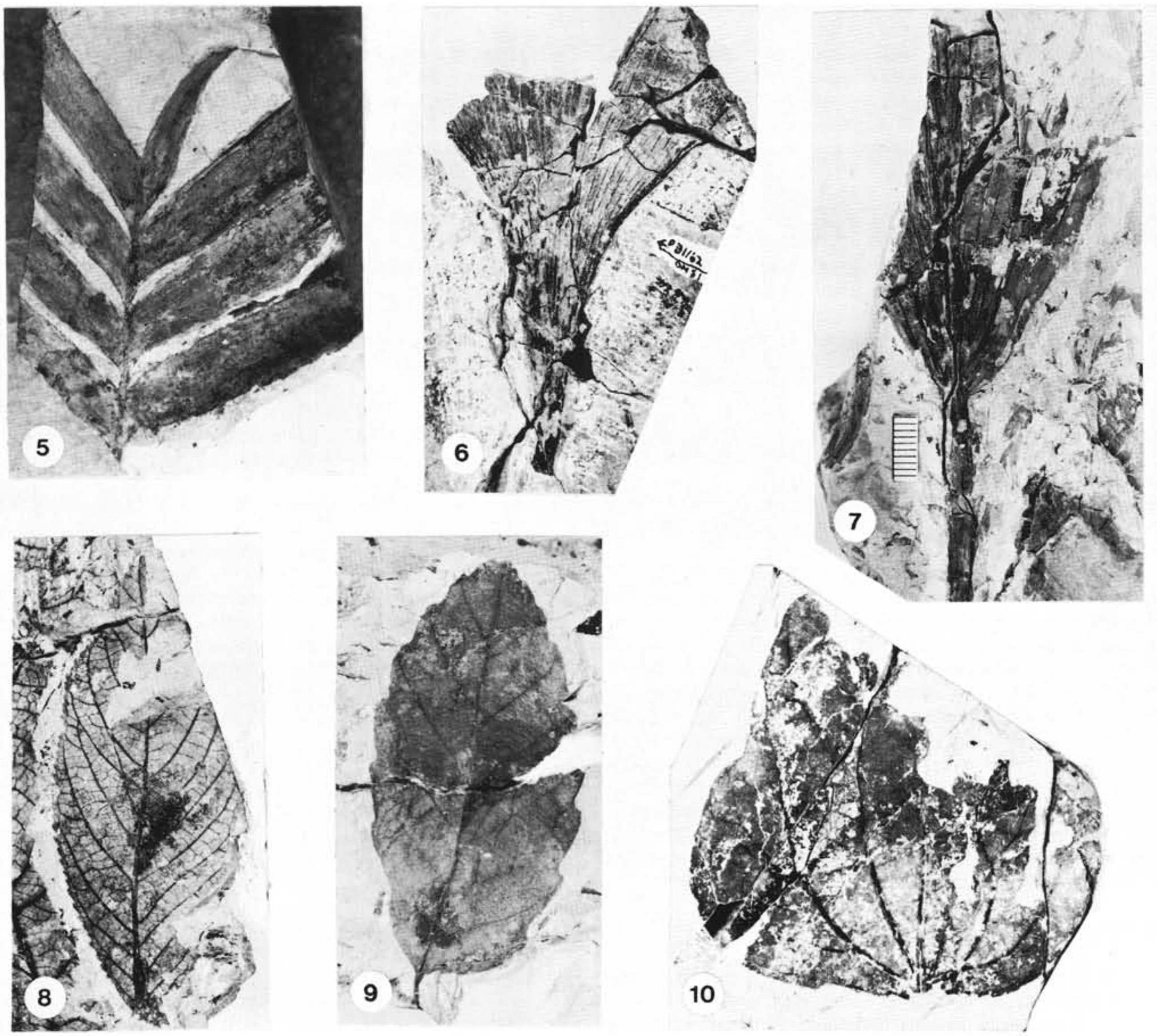
New identifications apply to two of the taxa figured by Bones (1979). Fruiting heads formerly thought to be *Altingia* (Bones, 1979, plate 2, Figure 5) have been shown to be *Platanus* (Manchester and Dilcher, 1980). Specimens figured as unidentified endocarps by Bones (1979, plate 6, Figures 1 and 2) have since been identified as *Tapiscia.*

ENVIRONMENTAL CONSIDERATIONS

The arid, semidesert conditions prevailing in the Clarno Basin today contrast strikingly with the environment reflected by the middle Eocene Nut Beds flora. Analysis of the floral assemblage indicates that the region was tropical or subtropical in the mid-Eocene. Two independent approaches have been used to assess the paleoenvironment: (1) the distribution and climatic requirements of related modern taxa, and (2) analysis of leaf form and correlation with environment.

A large portion of the identified taxa of the Nut Beds flora (Table 1) are chiefly tropical in their distribution today. *Dioon,* Palmae, *Alangium, Tapirira, Astronium,* Icacinaceae, Anonaceae, Menispermaceae, *Meliosma, Engelhardia, Castilla, Tetrapteris,* Sterculiaceae and Lauraceae are families and genera whose present-day species are mostly or exclusively restricted to tropical regions of Central and South America, southeast Asia, and (more rarely) Africa. The occurrence of these taxa in the Nut Beds suggests that the climate was warm, moist, and equable. In addition, there is a relatively high proportion of vines, lianas, and epiphytes (Vitaceae, Icacinaceae, *Tetrapteris, Hydrangea,* and others). These growth habits are most prevalent in tropical rain forests. Some of the identified genera, such as *Pterocarya* and *Ginkgo,* are absent from subtropical and tropical environments today. Presumably, the modern species of these genera have ecological tolerances which differ from those of the fossil species.

Analysis of leaf physiognomy also supports the interpretation that the Nut Beds flora was a tropical rain forest. This method of paleoclimate determination is based upon the observation that various foliage characteristics of modern



Figures 5-10. Fossil leaves from the Nut Beds. Natural size. 5. Dioon, *a cycad common in the Clarno Formation.* 6. Ginkgo, *the maidenhair tree.* 7. Sabalites, *a small fan palm frond.* 8. Pterocarya, *leaflet of the walnut family.* 9. Quercus, *oak.* 10. cf. Odontocarya, *a member of the moonseed family.*

floras, such as leaf size and margin type, tend to reflect the environment of growth. Species growing under tropical rain forest conditions typically possess large leaves with entire margins, while species adapted to temperate forests tend to have small leaves with serrate margins (Bailey and Sinnott, 1916; Wolfe, 1971). Forty-five of the 75 dicot leaf species recognized in the Nut Beds (considering unidentified as well as identified species), or about 60 percent, are entire margined (M. Muldoon, 1980, unpublished investigation). This figure falls well within the range of values suggested by Wolfe (1969, 1971) for paratropical rain forests, such as those growing today in lowland Taiwan. In contrast, temperate forests, such as those of Oregon's Willamette Valley, typically average from 10 to 40 percent entire-margined species. The high proportion of Nut Beds species with large leaves is also indicative of warm mesic conditions.

The suggestion of subtropical to tropical rain forest is also supported to some degree by wood structure. Most of the woods exhibit diffuse porosity, a condition which is most prevalent in tropical environments. However, the occurrence of distinct growth rings in most of the woods suggests definite seasonality.

EVOLUTIONARY IMPLICATIONS

The angiosperms, or flowering plants, are the most recently evolved major group in the plant kingdom, yet they have become the dominating element in most of the world's present-day vegetation. The initial evolutionary radiations of the angiosperms are recorded in upper Lower to lower Upper Cretaceous rocks (Hickey and Doyle, 1977). Early angiosperm floras are difficult to interpret because most of the taxa represent extinct groups whose relationships with modern families have been obscured by evolution. Successively younger floras become easier to interpret as the lines leading to modern genera and species become recognizable.

Investigation of the Nut Beds flora provides an opportunity to assess the evolutionary status of selected angiosperms

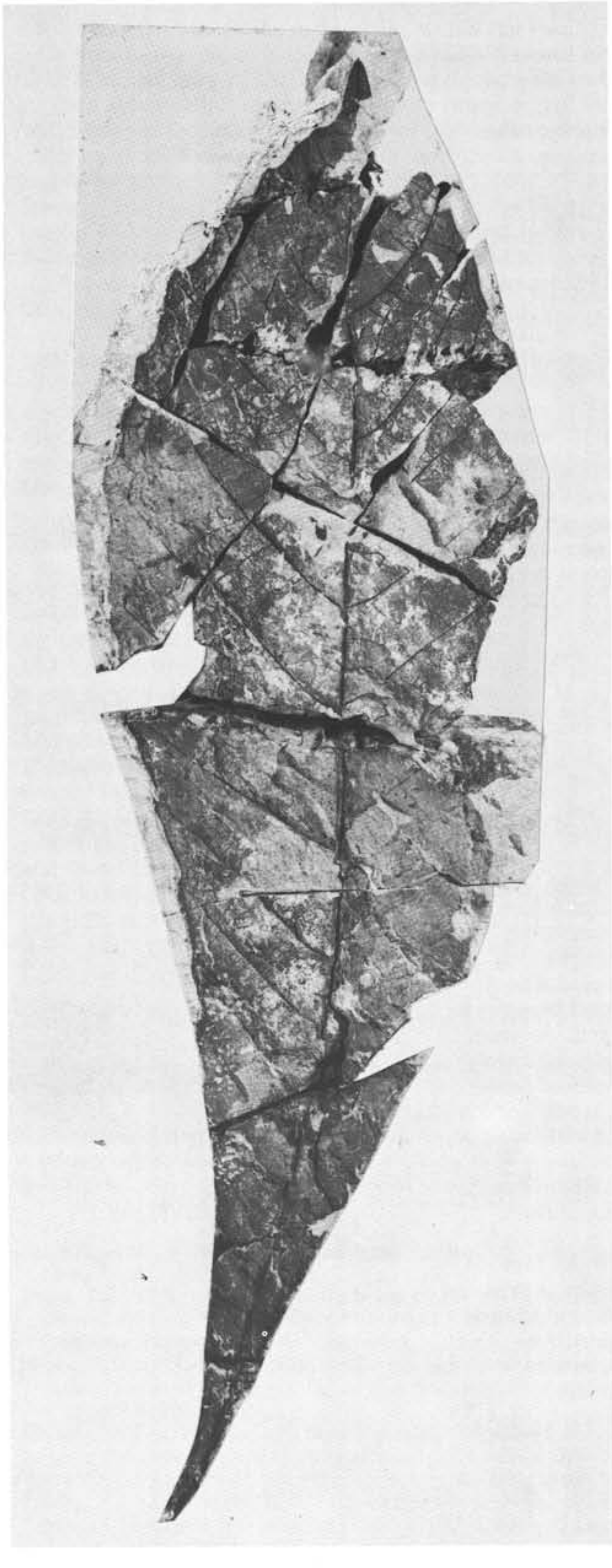


Figure 11. Meliosma. *A common leaf type in the Clarno Formation. Today this genus occurs in tropical Asia and Central and South America. Natural size.*

during the Eocene, which was about midway between the initial radiation of angiosperms and the present day. Due to the availability of several organ types in the Nut Beds, it is possible to conduct multiple-organ investigations of modernization in various angiosperm taxa during the middle Eocene.

As is evident from the foregoing sections of this paper, in which many of the fossils have been assigned to extant genera, the Nut Beds included many taxa which were well advanced along modern lines. This may give a false first impression of the flora, however. The Nut Beds flora actually shows a range in levels of modernization, including nearly identical forms, modern species, and forms belonging to extinct genera.

Most of the Nut Beds taxa appear to be extinct at the species level. One possible exception is a species of *Meliosma* represented by leaves, wood, and fruits from the Nut Beds. Based on careful analysis of these organs, the fossil species seems to be conspecific with the living species, *Meliosma simplicifolia* of Asia (Manchester, 1980b).

Although many of the Nut Beds taxa can be placed in modern genera (*Quercus, Platanus, Juglans, Vitis,* and others), it is frequently demonstrable that extinct species, or even subgenera, are represented. For example, Scott (1954) showed that the walnut, *Juglans clarnensis,* was an extinct species intermediate in fruit morphology between two modern sections of the genus *Juglans.* The Nut Beds walnut bore nutshells resembling those of the section *Rhysocaryon* but seeds characteristic of section *Cardiocaryon.*

Several extinct genera are known from the Nut Beds, including *Odontocaryoidea, Chandlera, Palaeonyssa* (Scott, 1954), *Langtonia* (Bones, 1979), *Triplochitioxylon* (Manchester, 1979); and *Chattawaya* (Manchester, 1980a). Some of these, such as *Langtonia,* appear to represent genera with no direct modern descendants. Others, such as *Odontocaryoidea* and *Triplochitioxylon,* may represent lineages which gave rise to similar but distinct genera that are still living today, such as *Odontocarya* and *Triplochiton.*

From this preliminary analysis, it is apparent that the elements of the Nut Beds flora varied in their evolutionary status. Some families, such as the Sabiaceae, Fagaceae, and Juglandaceae, are represented by species which are assignable to present-day genera, suggesting that they existed in the Eocene much as they do today and that relatively little post-Eocene evolution has occurred. Other families, such as the Menispermaceae and Sterculiaceae, are characterized by species which must be placed in extinct genera, suggesting that the morphological features characteristic of modern genera were still evolving in the middle Eocene.

Current research focuses on plant families which are represented in the Nut Beds assemblage by two or more organ types. It is of interest to know which organs in a given family or genus were more advanced and which were less advanced (relative to the condition in modern species) in the Eocene. This type of research requires intensive morphological and anatomical comparison with the living species of the family or genus under consideration.

One of the present areas of study involves the sycamore family, Platanaceae, which is represented in the Nut Beds assemblage by wood, leaves, and infructescences (fruiting structures) (Manchester and Dilcher, 1980). Since only one species of each organ is present in the large array of fossils from the Nut Beds, it is assumed that the organs probably represent the same biological genus and species. This assumption is supported by the fact that these organs also occur together in other Clarno localities. The infructescences of this plant (figured as *"Altingia"* in Bones, 1979) are common in the Nut Beds. They consist of fruiting heads or "seed balls" and were borne in strings of up to five, as in several modern species

Table 1. List of plant remains identified from the Clarno Nut Beds.

Family	Genus	Common name or comment	Organs represented
Equisetaceae	*Equisetum*	Horsetail	Stem, rhizome, cone
Dennstaedtiaceae	*Dennstaedtiopsis*	Fern	Petiole
Polypodiaceae	*Acrostichum*	Fern	Petiole
Cycadaceae	*Dioon*	Cycad	Leaf (Figure 5)
Ginkgoaceae	*Ginkgo*	Maiden hair tree	Wood[2], leaf (Figure 6)
Pinaceae	*Pinus*	Pine	Wood, pollen
Taxodiaceae	undetermined	Sequoia family	Wood
Palmae	*Palmoxylon*	Palm	Wood
	Palmocarpon	Palm	Fruit[6]
	Sabalites	Palm	Leaf (Figure 7)
Alangiaceae	*Alangium*	Tropical tree	Fruit[6]
Anacardiaceae	*Tapirira*	Cashew family	Wood[3]
	Astronium	Tropical tree	Wood
	Dracontomelon	Tropical tree	Fruit[6]
Anonaceae	*Anonaspermum*	Custard apple family	Seed[6]
Burseraceae	*Bursericarpum*	Torchwood family	Fruit[6]
Cercidiphyllaceae	*Cercidiphyllum*	Katsura tree	Wood, leaf, fruit
Cornaceae	*Mastixioidiocarpum*	Extinct genus	Fruit[1]
	Langtonia	Extinct genus	Fruit
Fagaceae	*Quercus*	Oak	Wood, fruit[6], leaf (Figure 9)
	Castanea	Chestnut	Leaf
Icacinaceae	*Paleophytocrene*	Tropical vine	Fruit[1]
Juglandaceae	*Juglans*	Walnut	Fruit[1]
	Pterocarya	Wingnut	Leaf (Figure 8)
	Engelhardia	Tropical tree	Wood, fruit[6]
Lauraceae	*Laurocarpum*	Avocado family	Fruit[1]
	Cinnamomophyllum	Avocado family	Leaf
	Ulminium	Avocado family	Wood
Leguminosae	*Tetrapleuroxylon*	Acacia family	Wood
Magnoliaceae	*Magnolia*	Magnolia	Leaf, seed[6]
Malpigiaceae	*Tetrapteris*	Tropical vine	Fruit
Menispermaceae	*Chandlera*	Extinct moonseed	Fruit[1]
	Odontocaryoidea	Extinct moonseed	Fruit[1]
	Dipoclisia?	Moonseed family	Fruit
	Tinospora?	Moonseed family	Fruit
Moraceae	*Ficoxylon*	Fig family	Wood
	Castilla	Fig family	Leaf
Platanaceae	*Platanus*	Sycamore	Wood, leaf, fruit
Rhamnaceae	*Berhamnophyllum*	Buckthorn family	Leaf
Sabiaceae	*Meliosma*	Aguacatilla	Wood, leaf (Figure 11) Fruit[6]
Sapindaceae	undetermined	Sapindus family	Seed[6]
Saxifragaceae	*Hydrangea*	Popular ornamental	Fruit
Staphyleaceae	*Tapiscia*	Bladdernut family	Seed
Sterculiaceae	*Triplochitioxylon*	Extinct tree	Wood[4]
	Chattawaya	Extinct tree	Wood[5]
Ulmaceae	undetermined	Elm family	Wood, leaf
Vitaceae	*Vitis*	Grape	Seed[6]
	Parthenocissus	Vine	Seed[1]

[1]Described by Scott, 1954.
[2]Described by Scott and others, 1962.
[3]Described by Manchester, 1977.
[4]Described by Manchester, 1979.
[5]Described by Manchester, 1980a.
[6]Figured in Bones, 1979.

of sycamore. Each of the many fruits within the fossil seed balls bore five seeds, as in the modern species *Platanus orientalis*. The similarity of the fossil wood and seed balls to the modern species of *Platanus* suggests that these organs were well advanced by the Eocene. The leaves (cover photo), on the other hand, are of an extinct type with more lobes and smaller angles of primary vein divergence than in extant *Platanus* species. The Nut Beds plant thus appears to be an extinct species with wood and fruits essentially identical to those of living species and distinctive leaves. This suggests that leaves in the Platanaceae have been more plastic, or less conservative, in their evolution than the wood and fruits.

As investigation of various organs and taxa from the Nut Beds continues, it will be possible to refine our understanding of the evolutionary status of various angiosperm families and genera at a point in time about 48 million years ago. Hopefully, this work will stimulate other workers to apply similar methodologies to the study of well-preserved angiosperm floras of other ages and in other parts of the world.

ACKNOWLEDGMENTS

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Note to the reader:

The absolute age of the boundary between the John Day and Clarno Formations and the stratigraphic and structural relationships of the two formations will be discussed in an upcoming issue of *Oregon Geology* in an article entitled, "A Mafic Dike System in the Vicinity of Mitchell and Its Bearing on the Timing of Clarno-John Day Volcanism and Early Oligocene Deformation in Central Oregon," by Edward M. Taylor, Department of Geology, Oregon State University, Corvallis, Oregon. □

Nickel: The strategic metal Oregon supplies to the rest of the United States

by Jerry J. Gray, Economic Geologist, Oregon Department of Geology and Mineral Industries

What strategic metal does Oregon supply to the rest of the United States?

Nickel. Oregon has the only producing nickel mine in the United States.

How much of the nation's demand for nickel does Oregon supply?

Oregon's annual production of contained nickel in ferronickel (a combination of 50 percent iron and 50 percent nickel) ranges from 14,000 to 16,000 tons, which is 6 to 10 percent of the nation's demand for nickel. Scrap accounts for another 20 to 30 percent of the annual consumption; the rest is imported.

Why is nickel called a strategic metal?

Nickel is vital to the iron and steel industry. Nickel's greatest value is in alloys with other elements, where it adds strength and corrosion resistance to steel over a wide range of temperatures. Without nickel, our modern-day society would not be possible.

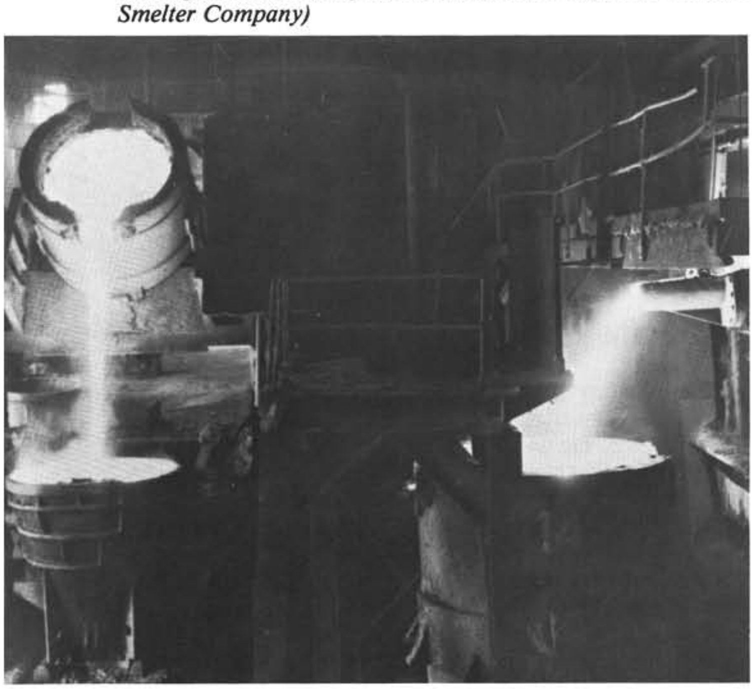
Where in Oregon is nickel ore mined and smelted?

The ore body being mined is on top of Nickel Mountain. The smelter is at the foot of the mountain. Nickel Mountain is located 4 mi west of the town of Riddle in southwestern Douglas County in southwestern Oregon.

How did the mine and smelter come into being?

In early 1953, two subsidiaries of the M. A. Hanna Company signed a Federal contract to build a nickel smelter and to develop the deposit of nickel ore at Nickel Mountain for the national stockpile. The firm was to furnish 95 to 125 million lbs of contained nickel in ferronickel at a price of 79.39¢ per lb for the first 5 million lbs and 60.5¢ per lb thereafter. In later years, when the Federal government sold the ferronickel from its stockpile, it realized over $2.00 per lb.

Left side of photo shows slag being poured from reaction ladle into slag pot. Right side shows molten ore being poured from melting furnace into reaction ladle for continuous melting batch reaction process. (Photo courtesy Hanna Nickel Smelter Company)



Who operates the mine and smelter?

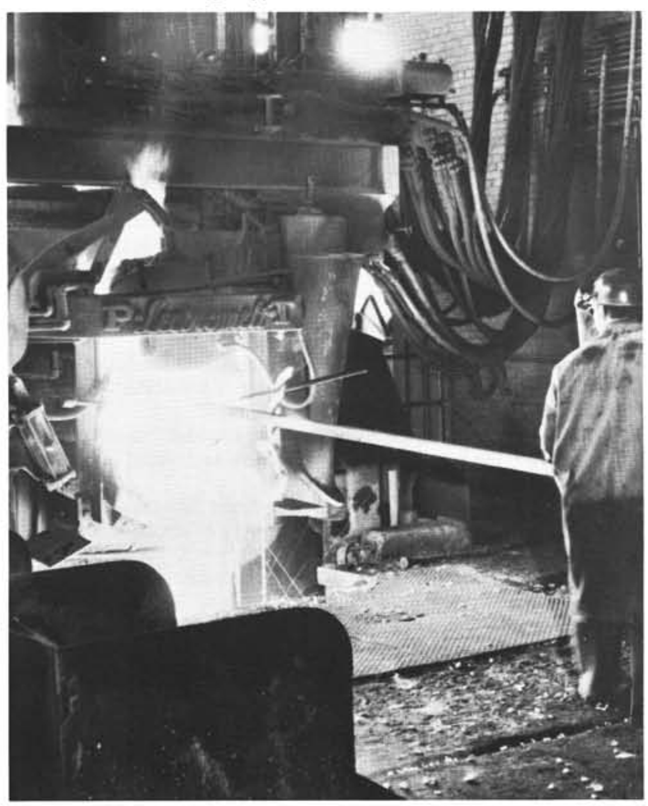
The Hanna Mining Company and Hanna Nickel Smelting Company began production of ferronickel in July 1954. This ferronickel was the first to be produced in the United States from domestic ores. The companies have operated on an around-the-clock schedule since that time, providing steady, year-round work for approximately 600 employees.

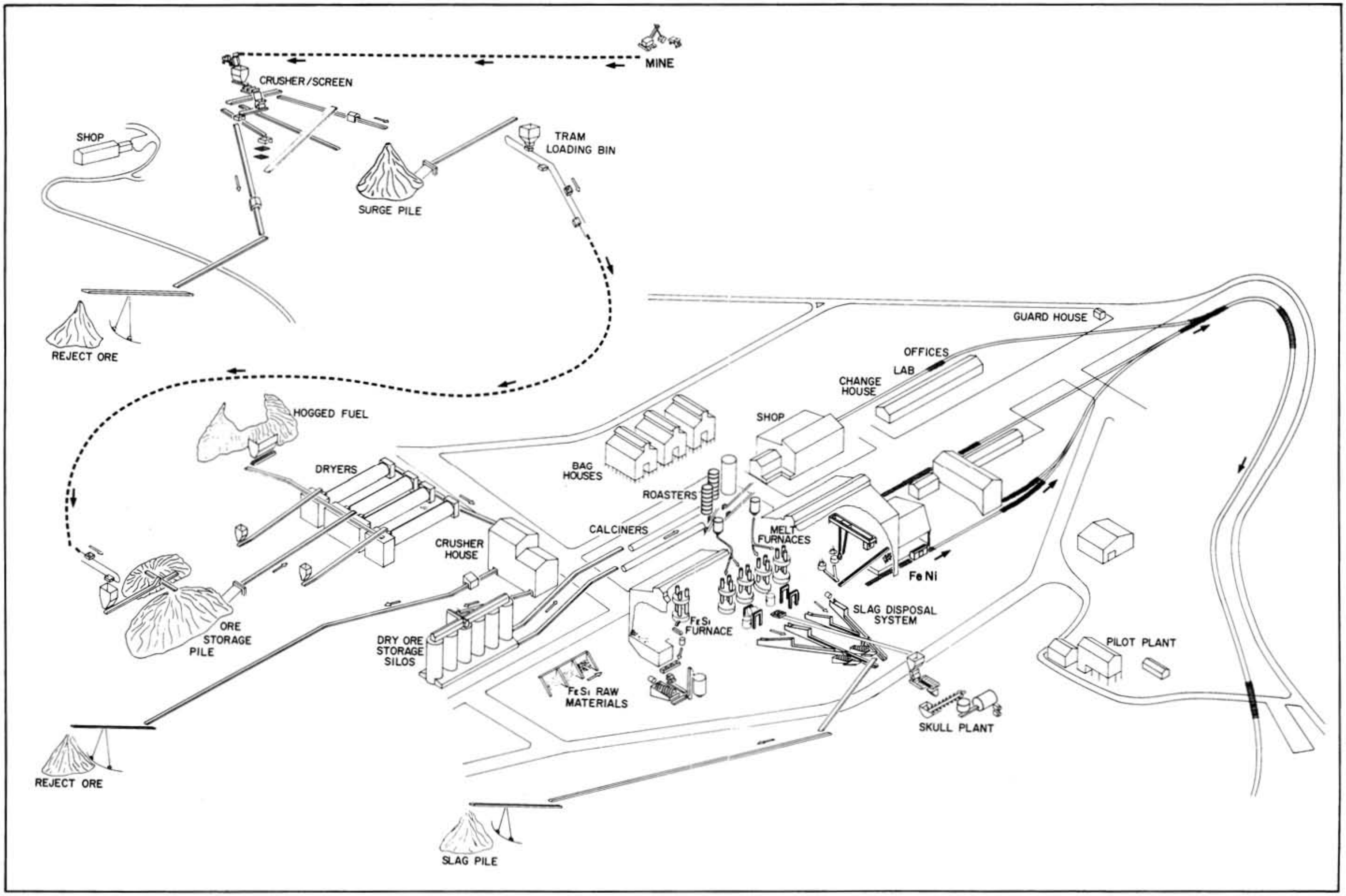
What kind of deposit is at Nickel Mountain?

The Nickel Mountain ore deposit is a laterite, with garnierite its chief mineral. Nickel Mountain itself appears to be an erosional remnant of an overthrust sheet containing peridotite which, when fresh, contains 0.2 percent nickel but is now weathered. The ore body was formed by the leaching and transporting downward of the nickel during the process of weathering.

The ore body is divided into three zones: (1) soil (bright red at the surface, grading into a yellow-brown at depth); (2) saprolite (light- to dark-green weathered peridotite); and (3)

Slagging off a refining furnace. (Photo courtesy Hanna Nickel Smelter Company)





Process whereby nickel is mined and smelted at Nickel Mountain, southwestern Douglas County, southwestern Oregon. (Drawing courtesy Hanna Mining Company and Hanna Nickel Smelting Company) box works (yellow-brown to bright-green). The soil contains 20 percent of the nickel resource, the saprolite 70 percent, and the box works the remaining 10 percent.

The deposit is made of six major areas that cover a total of approximately 600 acres. The average nickel grade in the crude ore presently under active development is approximately 1.0 percent.

How is the deposit mined?

The mining is by the multiple-bench open-pit method. The benches are at least 50 ft wide, with 20-ft vertical faces. Up to 80 percent of the ore can be dug without blasting. Conventional drilling and blasting are used on the remaining 20 percent. Pit-run ore is loaded by diesel shovels into 60-ton diesel trucks and hauled to the screening plant.

Can the ore be upgraded by flotation or other standard beneficiation?

No. Because of the mineralogy of the ore, the only upgrading that can be done must be based on the physical characteristics of the ore, such as softness or hardness, fineness or coarseness, and/or color.

How is the ore upgraded?

As the ore is being mined, large boulders called pit rejects are separated from the ore by the shovel operator and ultimately deposited on waste dumps. The boulders, which are mostly unweathered peridotite, contain low amounts of nickel. More upgrading takes place at the screening-crushing plant. The trucks dump the ore directly into the screening-plant feed hopper. A separation is made according to the size of the material, with the smaller going directly to the tramway surge pile and the larger to the crusher. After crushing, the material is visually classified and then directed either to the tramway or to the reject stockpile.

How does the ore get from the screening-crushing plant on top of Nickel Mountain to the smelter at the foot of the mountain?

An 8,300-ft tramway with a 2,000-ft drop connects the screening-crushing plant with the smelter. At the tramway, the ore is fed to the loading terminal, where it is loaded automatically into 50-cu-ft tram cars and conveyed downhill to the smelter storage stockpile.

The tramway runs continuously, carrying ore in the upright tram cars and returning the empty cars in an inverted position. The ore is discharged onto the stockpile by inverting the cars at the lower end of the tramway. A speed of 600 ft per minute is maintained by the braking action of the two 300-horsepower generators driven by the weight of the loaded tram cars. The braking action of the generators produces approximately 500 horsepower, which is used in the generation of electricity for the operation of the mine facilities.

How is nickel produced from the ore?

Ore from the stockpile is processed at the smelter to produce ferronickel containing approximately 50 percent nickel. Steps in the process include reclaiming of ore, drying, screening of fines, rejecting of lean rock by screening, crushing, sampling, calcining, melting, reducing to ferronickel, refining, casting, and recovering skull metallics.

The process whereby the ore is melted and reduced and the nickel refined is the most spectacular part of the entire operation. The ore is fed into the melting furnaces by gravity and further heated to a temperature of approximately 3,000° F., where it melts. The molten ore is then poured from the melting furnaces into ladles where the nickel extraction occurs.

Reduction of nickel and iron is accomplished by the Ugine process, which consists of adding a reducing agent containing metallic silicon to an oxide ore in the presence of molten ferrous metals and using vigorous mixing action for good contact of reductant and ore. In Hanna's smelter, crushed ferrosilicon containing 48 percent silicon is used to extract the metal. The ferrosilicon is produced in a separate electric furnace in the smelter. During a mixing cycle, nickel and iron are extracted from the molten material through a chemical reaction between the nickel ore and the ferrosilicon. The ferronickel is allowed to settle to the bottom of the ladle. The slag is poured off and granulated with high-pressure water jets. The nickel is then poured off into pigs for shipment.

What is done with the slag?

After the slag is granulated, it is transported by water to a large green slag pile. A small portion of the slag is sent to another company that screens the slag into different sizes, bags it, and ships it to California and elsewhere for use in sandblasting. The slag is also used for fill and sanding of highways.

How long will this operation last?

Reclamation plans on file with the Oregon Department of Geology and Mineral Industries state that mining will be going on at Nickel Mountain until at least the year 2003. Other deposits somewhat lower in grade are known to exist in Curry and Josephine Counties and might provide a source of ore after Nickel Mountain has been mined out.

Table 1. Summary of Hanna Mining Company's Riddle operation for 1979

Production—Ferronickel	42,250,415 lbs.
Nickel contained	21,787,960 lbs.
Ore mined	3,822,587 tons
Payroll	$16,000,000
Electrical power and fuels	$ 9,000,000
Environmental cost	$ 504,400
Property taxes	$ 298,400
County royalty fees	$ 275,000

What effect has the Riddle operation had on the local economy?

Employment in Douglas County is mainly timber dependent, which means that employment has had seasonal ups and downs and in the past has experienced wild swings up and down caused by the national demand for wood products. Because the plant provides year-round employment for more than 600 workers, the Riddle operation tends to provide a steady base level for the local economy. □

Industry expenditures for oil and gas exploration in Oregon, 1976-1980

1980	$25,700,000
1979	10,695,000
1978	4,608,000
1977	2,000,000
1976	2,000,000

ABSTRACTS

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

THE STRUCTURE AND STRATIGRAPHY OF THE COLUMBIA RIVER BASALT IN THE HOOD RIVER VALLEY, OREGON, by Susan Timm (M.S., Portland State University, 1979)

The Hood River Valley, located 100 km east of Portland, Oregon, is in the transition zone between two geologic provinces – the High Cascades and the Columbia Plateau. The entire valley is probably underlain by Columbia River Basalt, but it crops out only on steep hillsides and in stream valleys. The base of the basalt is not exposed in the thesis area. The basalt is overlain by Pliocene and Quaternary basalt and andesite, volcanic sediments, and glacial debris.

The stratigraphy of the Columbia River Basalt is useful in determining the path of the basalt flows into western Oregon, in mapping the structure, and in reconstructing the tectonic development of the northern Oregon Cascades.

The detailed stratigraphy of the Columbia River Basalt in the Hood River Valley was determined through petrography, trace element chemistry, remanent magnetic polarity (RMP), and correlation of known flows in the field. The structure was determined by field observations and photo lineations and from stratigraphic correlations throughout the Hood River Valley.

The Columbia River Basalt exposed in the Hood River Valley belongs to the Yakima Basalt Subgroup and comprises the High MgO and the Low MgO geochemical types of the Grande Ronde Basalt and the Frenchman Springs and Priest Rapids Members of the Wanapum Basalt. Two remanent magnetic polarity boundaries are exposed in these basalt flows. They are the N2/R2 boundary within the Low MgO Grande Ronde flows and the R3/N2 boundary between the Priest Rapids and the underlying Frenchman Springs Members of the Wanapum Basalt.

The total thickness of the exposed Yakima Basalt is approximately 480 m. Extensive palagonite at the flow contacts and variation of thickness of groups of flows indicate that part of the area was a topographic low during much of the time the flows accumulated.

Two linear trends dominate the area. East- to northeast-trending faults and folds are cut by younger northwest-trending faults and dikes. An anticline plunges to the east across the southern part of Middle Mountain. A thick breccia zone in the Neal Creek drainage southeast of Middle Mountain marks a northeast-trending fault. The northeast structures are cut by numerous northwest-trending antithetic faults. The faults occur in a step-like pattern across the valley. The Hood River Fault bordering the east side of the valley has a right-lateral as well as vertical component.

The Hood River Valley does not appear to be a graben; rather it consists of many tilted blocks hinged to the southwest and dipping to the northeast. Flows on Middle Mountain on the west side of the valley are at the same elevation as correlative flows on the east side of the Hood River Fault.

GEOLOGY OF THE SOUTH-CENTRAL MARGIN OF THE TILLAMOOK HIGHLANDS; SOUTHWEST QUARTER OF THE ENRIGHT QUADRANGLE, TILLAMOOK COUNTY, OREGON, by Kenneth Allan Cameron (M.S., Portland State University, 1980)

The Tillamook Highlands is a largely unmapped volcanic pile located in the north end of the Coast Range of Oregon. The 36 sq mi of T. 1 N., R. 8 W., on the south-central margin of the Highlands, were chosen for detailed study.

The study area is composed of Eocene-age sedimentary and volcanic units which were deposited in a filling basin. The lowest units were deposited in moderate to deep marine waters; the uppermost were deposited subaerially.

Stratigraphically lowest is a unit composed of 800 m of rhythmically bedded, poorly indurated, sparsely fossiliferous, brown siltstone with rare interbeds of volcanic lithic sandstone. On the basis of fossil evidence (the pelecypods *Glycimeris* sp. and *Acila* sp.), it is believed that this material was deposited in moderate to deep marine water.

Conformably overlying the siltstone are 900 m of submarine volcaniclastic deposits with minor sedimentary sub-units and a large tuff lens. The major rock type is a zeolite-cemented flow breccia. Minor amounts of pillow lavas and hyaloclastites are found in the upper one-third of the unit. The sedimentary sub-units, consisting of immature volcanic feldspathic litharenites and tuffaceous shales, have a total thickness of 35 m. The shales are very fossiliferous, containing remains of the plants *Cornus* sp. (dogwood), *Picea* sp. (spruce), *Chamaecyparis* sp. (cedar), and *Ailanthus* sp. (Tree of Heaven) deposited in shallow water. These plants show that a warm, temperate climate existed in this area during the Eocene. The tuff lens is a deposit of water-worked crystal-vitric tuff. It has a maximum thickness of 100 m and an areal extent of over one square kilometer. It is characterized by an abundance of large (up to 3 cm) euhedral clinopyroxene crystals.

Conformably overlying the volcaniclastic unit are at least 900 m of subaerial pyroxene basalt in the form of individual flows 20 to 30 m thick. The basalt and volcaniclastic material interfinger for 100 m at the contact. Major oxide analysis shows that these two units are chemically identical and are probably the product of the same parent magma. The differing habit of the units is the result of differing environments of deposition; the volcaniclastics are submarine and the basalts subaerial.

The contact represents sea level during the extrusive period.

A large diabasic sill has intruded the marine siltstones. It has a glassy chilled margin with rudimentary columnar jointing which grades into white or green diabase with an ophitic core. Total thickness of this unit exposed in the study area is 300 m.

Structure is dominated by a regional dip of 18° to the northwest which is complicated by three generations of post-dip faulting. The first generation trends northwest, the second northeast, and the third east-west. All faults are vertical and show no strike-slip component.

Dikes with thicknesses over one meter are aligned, trending N. 30° W. This is a result of the regional stress pattern at the time of intrusion, probably compressional stress with σ_1 oriented east-west.

GEOLOGY AND METAMORPHIC PETROLOGY OF THE ELKHORN RIDGE AREA, NORTHEASTERN OREGON, by Eric Jordan Stimson (M.S., University of Oregon, 1980)

An investigation into the nature of regional and contact metamorphism of a part of the Elkhorn Ridge Argillite in northeastern Oregon and an associated greenstone body was carried out in the vicinity of the Late Jurassic Bald Mountain batholith. The mineralogy of the greenstones progresses from assemblages typical of the lower greenschist facies in the regionally metamorphosed rocks, through three zones of contact metamorphism as the batholith is approached. Pyroxene hornfels facies assemblages are developed in the highest grade rocks.

Clinochlore-bearing serpentinites are recrystallized to assemblages containing forsterite, enstatite, tremolite, and green spinel within 200 m of the batholith.

A greenstone body, previously mapped as a metamorphosed gabbroic intrusion, is shown to be a pile of intrusive and extrusive basic and intermediate rocks that were originally in depositional contact with the adjacent argillites. Post-depositional folding and thrust faulting has obscured this relationship.

THE GEOLOGY AND PETROLOGY OF THREE FINGERED JACK, A HIGH CASCADE VOLCANO IN CENTRAL OREGON, by Ellen Ingraham Davie, II (M.S., University of Oregon, 1980)

The eruptive history of Three Fingered Jack is characteristic of many of the coherent volcanoes of the High Cascade Range. First, a pyroclastic cone formed on the underlying shield lavas and was then followed by flows and pyroclastic material which accumulated to form the main cone. Numerous dikes radiate outwards from a late stage plug of micronorite that slightly deformed adjacent layers of tephra. Subsequent flows of olivine-augite basalt occurred on the north and south flanks of the volcano.

Major- and trace-element abundances indicate that in the area of Three Fingered Jack different units of flows represent discrete batches of parental magma. Jorn Lake basalt of the underlying shield and basaltic andesite of Three Fingered Jack are exceptions to this general rule. Petrology indicates that these lavas crystallized at high and low pressures; basaltic andesite differentiated from basalt as a result of prolonged crystal fractionation. □

Don't trespass on mining claims

High mineral prices and the onset of fine weather lure people out to roam spaces that may not be open, even though they appear to be. The public needs to be reminded that mining claims are property in the highest sense of the term. A patented claim has the same legal status as a house in town. Unauthorized entry on such land is prohibited as strongly as on any private premises. Trespassing can bring criminal prosecution.

The public may not be aware that unpatented mining claims are also private property, even though management of surface resources and vegetation is a function of a public agency such as the Bureau of Land Management or the U.S. Forest Service. The United States, its licensees, or permittees are required by law to avoid interference with the mining locator's prospecting, mining or processing activities, or activities reasonably incident thereto, as well as the miner's buildings, equipment, and improvements on the claim.

Both Federal and State law protect the miner against vandalism. It is unlawful to deface, remove, pull down, or injure or destroy, any location stake, side post, corner post, landmark, or monument, or to tear down, deface or alter any posted or written notice on a mining claim. Any damage to the miner's cabin or equipment or any breaking and entering or injury to his property is punishable as a crime. People who like to roam the great outdoors should be careful to obtain permission before they invade areas that have been segregated from the public domain, and even on the public domain they should remember to observe good manners towards public property also. □

—Bohemia Mine Owners Association

(New open-file reports, *continued from page 74*)

Open-File Report 0-80-10, *Preliminary Geology and Geothermal Resource Potential of the Alvord Desert Area, Oregon,* contains geothermal data from the Alvord Valley, which lies east of Pueblo and Steens Mountains in southeastern Oregon. Included in the 57-page text are total field aeromagnetic anomaly, audio-magnetotelluric apparent resistivity (27 and 7.5 hertz), and simple Bouguer gravity anomaly maps of the area. Accompanying the text are a one-color reconnaissance geologic map and a two-color preliminary geothermal resource map (scale 1:250,000). Cost of Open-File Report 0-80-10 is $7.00.

Previously announced open-file reports in this series include 0-80-2 (Belknap-Foley area of the central Western Cascades), 0-80-3 (Willamette Pass area of the central Western Cascades), 0-80-6 (northern Harney Basin), and 0-80-7 (southern Harney Basin), which sell for $5.00, $5.00, $7.00, and $10.00, respectively.

All of these open-file reports are available for inspection or purchase at the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. Payment must accompany orders of less than $20.00. □

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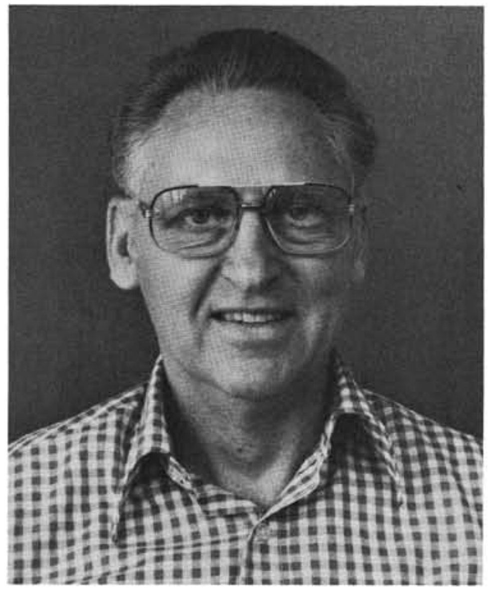
COVER PHOTO

Grand Canyon of the Snake River, forming the boundary between Oregon and Idaho. This area is one of many places in Oregon discussed in the third edition of *Geology of Oregon*, by Ewart M. Baldwin. A brief review of this new book appears on page 102. (Photo courtesy Oregon State Highway Division)

DOGAMI adds new petroleum geologist to staff

William L. King, Petroleum Geologist, joined the professional staff of the Oregon Department of Geology and Mineral Industries in March of this year. A native of Pennsylvania, King received his bachelor's and master's degrees in geology from the University of Pittsburgh.



William L. King

Prior to coming to Oregon, King was a geologist with Peoples Natural Gas Company, Pure Oil Company, and Humble Oil and Refining Company (Exxon). His work in the petroleum industry has taken him to Texas, Pennsylvania, California (onshore and offshore), Alaska, Mississippi, Louisiana, Oklahoma, and the United Kingdom.

King's responsibilities with DOGAMI include regulatory work related to oil, gas, and geothermal exploration and development in the State of Oregon. □

CONTENTS

Subduction-related origin of the volcanic rocks of the Eocene Clarno Formation near Cherry Creek, Oregon

by Jeffrey B. Noblett, Department of Geology, Colorado College, Colorado Springs, Colorado 80903

ABSTRACT

Terrestrial calc-alkaline volcanic rocks of the Eocene Clarno Formation in north-central Oregon appear to be a good example of subduction-zone magmatism. Mapping of an area along the John Day River near Cherry Creek showed that the many individual flows could be placed into three petrographic types. The earliest lavas are highly porphyritic two-pyroxene basaltic andesites. The key feature of the middle portion of the Clarno Formation is a group of nonporphyritic, quartz-bearing basaltic andesites which have also been noted as single units in other stratigraphic columns throughout the Clarno. The nature of their origin suggests they may be correlated as a time horizon across the Clarno. An angular unconformity and thick saprolite separate the gently folded lower Clarno beds from the much less voluminous upper Clarno volcanic rocks. A dome of hornblende andesite is the most notable feature of these later flows.

Textural and chemical evidence suggests that the porphyritic lavas formed as hydrous melts that rose from a subducted slab and interacted with the overlying mantle, whereas the nonporphyritic lavas formed by partial melting of anhydrous quartz eclogite followed by rapid ascent. New age data (Robinson, 1979, personal communication) suggest that the Clarno is older than 40-42 m.y. Subduction during this time was fairly rapid and at about a 30° angle. Estimated temperatures on the surface of this plate match temperatures at which the Clarno andesites could have formed. A model of magmatism arising from a shallowly dipping hydrous portion of the subducted plate, with one brief increase in dip (about 5°) generating the quartz lavas, can explain the general characteristics of Clarno volcanism.

INTRODUCTION

The Eocene Clarno Formation is located in north-central Oregon (Figure 1). It is a sequence of dominantly andesitic volcanic rocks that range in composition from basalt to rhyolite. Besides lava, the formation includes many intrusive feeders, volcanic breccias, mudflows, ash flows, and tuffaceous sediments of fluvial and lacustrine origin. Many of these units are characterized by rapid lateral and vertical variation. Previous workers on the Clarno Formation have concentrated on localized descriptions, as no regionally extensive unit that can be used for correlation had been found.

One of the thickest sequences of volcanic flows, intrusives, and sediments occurs between Cherry Creek and the mouth of Bridge Creek on the John Day River (Figure 1). The volcanic stratigraphy of this area was studied in detail by field mapping, petrography, and petrochemical analysis. One of the mapped units, the nonporphyritic quartz-bearing andesite, may prove to be a time horizon throughout the Clarno when its probable origin on a subducted plate is considered.

PREVIOUS WORK

The Clarno Formation lies unconformably on the Cretaceous marine Hudspeth and deltaic Gable Creek Formations (Oles and Enlows, 1971) and marks the end of marine deposition in central Oregon. Overlying the Clarno Formation are the more silicic fluvial and lacustrine tuffs of the John Day Formation and basalt flows of the Columbia River Basalt Group (Figure 2).

Summaries of Clarno lithology (Steere, 1954; Beaulieu, 1972) and reconnaissance mapping by Swanson (1969) present a picture of late Eocene terrestrial calc-alkaline volcanism. Petrochemical work (Rogers and Ragland, 1980) suggests that the Clarno Formation formed on thin continental crust and may be related to partial melting in the mantle.

Merriam (1901) first described Clarno rocks from typical exposures at Clarno's Ferry (present-day town of Clarno). He estimated that there were over 400 ft of dominantly eruptive materials, particularly rhyolite and andesite, with characteristic ashy shale and other tuffaceous sediments.

One of the thickest sequences of Clarno rocks was described by Waters and others (1951) in their investigations of the Horse Heaven mining district, situated alongside Cherry Creek. They established four units comprising 5,800 ft of section. Unit 1 consists of 600 ft of platy andesite interbedded with clays. Unit 2 contains 1,350 ft of tuffs, volcanic mudflows, and a few thin andesite flows and is partially equivalent to the lower sedimentary group of this study. Unit 3 has 1,750 ft of tuffaceous clay with a few andesite flows. Unit 4 is the 3,100-ft rhyolitic tuff layer. It includes 150 ft of andesite flows, one of which is equivalent to this study's nonporphyritic flows. A thick saprolite was developed on these units, and they were subsequently overlain unconformably by a second sequence of lavas considered post-Clarno by Waters and others (1951) but since placed in the Clarno Formation by Swanson and Robinson (1968).

Sporadic outcrops of Clarno-type rocks occur farther to the east, in the Canyon City quadrangle (Brown and Thayer, 1966). The northernmost Clarno exposure (Umatilla-Pilot Rock, Heppner district) is dominated by carbonaceous sediments and some andesite (Collier, 1914; Wagner, 1954; Hogenson, 1964).

AGE

One of the more interesting problems of the Clarno is its age. K-Ar ages range from 46 m.y. to 33 m.y. (see Walker and others, 1974, for a compilation). However, a date of 41.0 ± 1.2 or 43.0 ± 0.6 was obtained on a rock that is from one of the youngest flows from the upper portion of the Clarno Formation (Swanson and Robinson, 1968). Robinson carefully redated some of the "younger" Clarno rocks which appeared to be lower Clarno lavas and discovered they were actually about 50 m.y. old (1979, personal communication). In no case has a sample been younger than 41 m.y. This Eocene age fits well with the tectonic history as described in a later section.

DESCRIPTION OF ROCK UNITS

Near the confluence of Cherry Creek and the John Day River, the Clarno Formation is divisible into two groups of rocks separated by a thick saprolite and an angular unconfor-

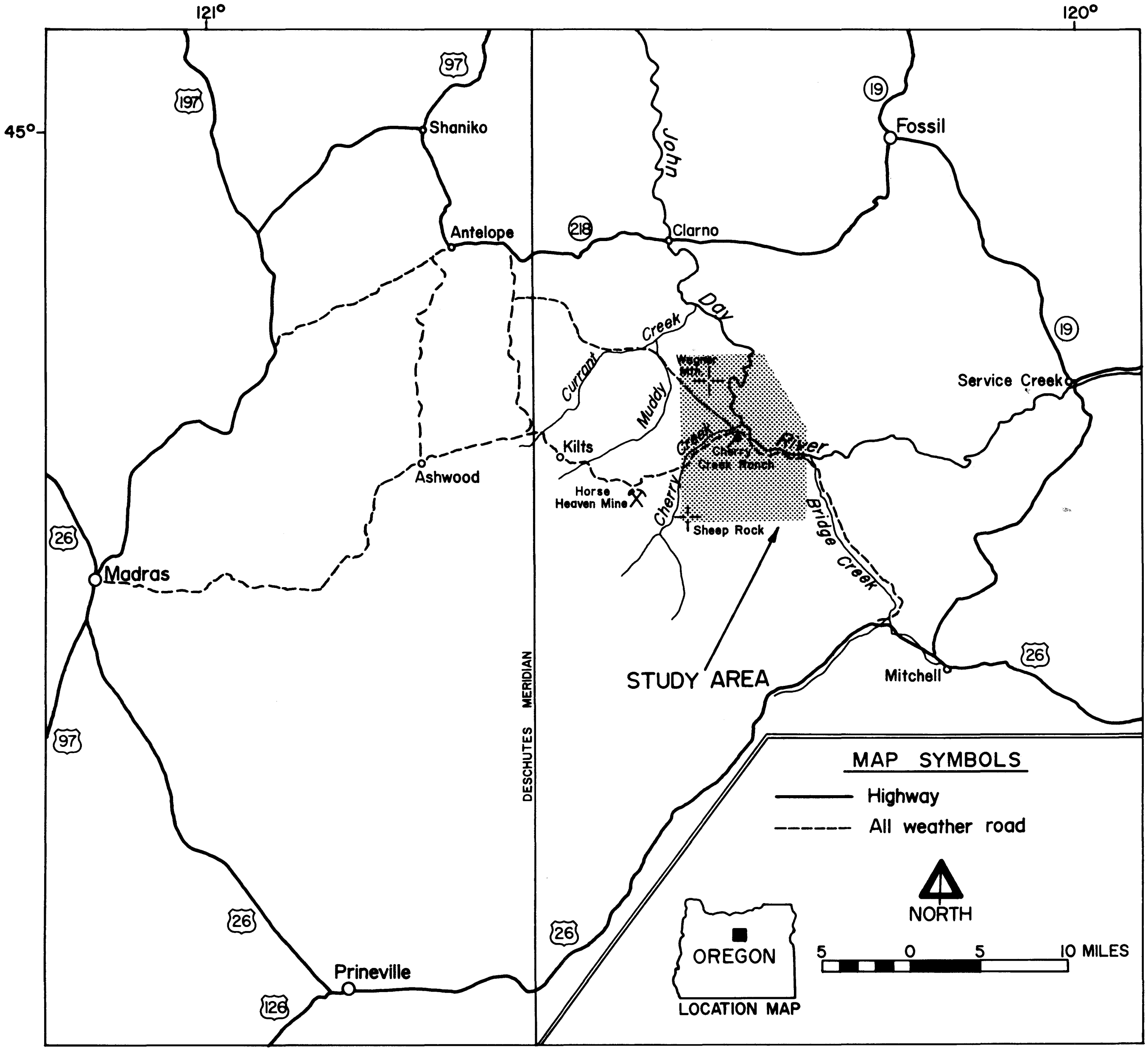


Figure 1. Map showing location of study area in north-central Oregon.

mity. The lower group, about 1 mi thick, comprises mudflows, andesitic lavas, and thick sedimentary clay and tuff sequences. The upper group is limited in extent to several basaltic and andesitic flows and domes. In this study, emphasis was on the petrography of volcanic rocks, and very little work was done on the sedimentary units. Major problems in identifying and mapping individual units were their extremely local and patchy nature and their frequently fine-grained textures, which made it necessary to use thin-section analysis to identify rocks from different units. With the exception of an extensive mudflow, few units extended for more than half a mile.

The terms "porphyritic" (greater than 10 percent phenocrysts), "subporphyritic" (6-10 percent phenocrysts), and "nonporphyritic" (less than 6 percent phenocrysts) are useful in classifying Clarno lavas into broad groups. Generally, porphyritic andesites have 25-30 percent phenocrysts of plagioclase and pyroxene. The nonporphyritic rocks have 2-3 percent phenocrysts usually of resorbed quartz and plagioclase. Division of these lavas into two petrographic types is most useful for discussing the origin of Clarno andesite. Characteristics of several of the prominent units are discussed below in stratigraphic sequence, beginning with the oldest unit (see Noblett, 1979, for details). A list of the Clarno units discussed in this paper appears in Table 1.

LOWER PORTION OF THE CLARNO FORMATION

The lowest unit, a 140-ft-thick basal sedimentary unit, includes a mudflow and conglomeratic sandstones which contain altered andesite fragments. This unit lies on the axis of an anticline and may not be the true base of the Clarno.

The basal unit is overlain by the first major outpouring of porphyritic andesite which occurs throughout the lower portion of the Clarno as a series of five units with an accumulated thickness of over 1,500 ft. These are holocrystalline lavas

Table 1. *Clarno Formation units discussed in this paper. A complete list of units and a geologic map showing their areal extent are found in Noblett (1979). Oldest units are at the bottom of the list; youngest units are on top.*

Nonporphyritic basaltic andesite
Hornblende andesite
Basaltic andesite
—Angular unconformity—
Thick saprolite
Subporphyritic basaltic andesites
Porphyritic andesite
Upper sedimentary unit (largely tuffaceous sandstone)
Nonporphyritic felsic hypersthene andesite
Nonporphyritic quartz-bearing andesite
Nonporphyritic olivine augite andesite
Nonporphyritic felsic glassy andesite
Middle sedimentary unit (varicolored tuffs, sandstone, local thin andesite flow, and local red and white basal tuff)
Middle porphyritic andesite
Lower sedimentary unit (tuffaceous sandstones and conglomerates, andesite and basalt flows, Cherry Creek fossil bed, pumiceous tuff)
Bouldery, hoodoo-forming mudflow
Porphyritic andesite
Porphyritic andesite
Altered tuff
Lowest porphyritic andesite
Basal sedimentary unit (mudflow and conglomeratic sandstones)

(about 30 percent phenocrysts), with phenocrysts of normally zoned plagioclase (An_{54-40}) that is often replaced by calcite and a clay, fresh augite, and hypersthene altered to either biotite or chlorite (Figure 3). Euhedral to stringy blebs of magnetite occur as phenocrysts. The groundmass is dominantly plagioclase, remnant pyroxene, and dusty magnetite, largely obscured by clay alteration. An extensive 100-ft-thick, altered red and white tuff unit lies between the two lowest flows.

A bouldery, 100-ft-thick, 3.5-mi-long, hoodoo-forming mudflow which proved to be the most useful unit for mapping was traced to an intrusion by the Cherry Creek ranch house (W¼ sec. 25, T. 9 S., R. 19 E.). The intrusion is the only hornblende andesite positively placed in the lower portion of the Clarno.

Stratigraphically above the mudflow are three tuffaceous fluvial and lacustrine sedimentary units, with a total thickness of over 2,000 ft, which were deposited throughout early Clarno time. The lowest sedimentary unit is an agglomeration of many tuffaceous sandstones and conglomerates and local andesite and basalt flows, and includes the famous fossil-leaf locale on Cherry Creek (Hergert, 1961) and the only patch of pumiceous tuff in the area. Either a local red and white tuff layer or a porphyritic andesite separates the lower from the middle sedimentary unit, which typically contains varicolored tuffs, sandstones, and local thin andesite flows.

Four nonporphyritic andesite flows with an accumulated thickness of over 1,000 ft (Figure 4) were erupted in rapid succession; this sequence contains no interbedded sediments and was probably contemporaneous with the middle sedimentary unit. Although these four flows are not covered by later Clarno lavas, their 20° dip and the lack of a thick saprolite beneath them places them in the lower portion of the Clarno. The oldest of these four, a felsic andesite unit, was erupted from the vent at Sheep Rock (SW¼ sec. 16, T. 10 S., R. 19 E.)

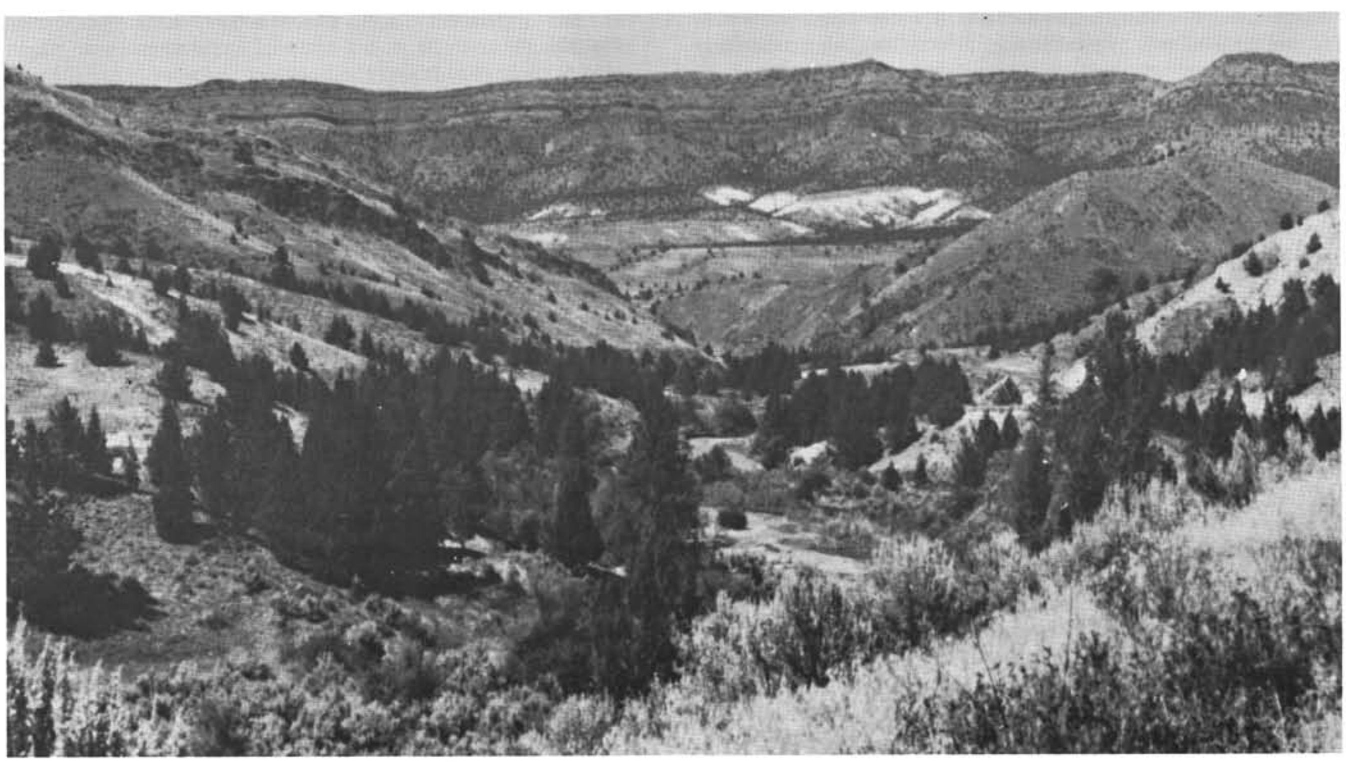


Figure 2. View northwest of Mitchell, Oregon, showing typical Clarno Formation lavas in foreground overlain by light-colored John Day Formation tuffs, which are in turn overlain by horizontal flows of the Columbia River Basalt Group.

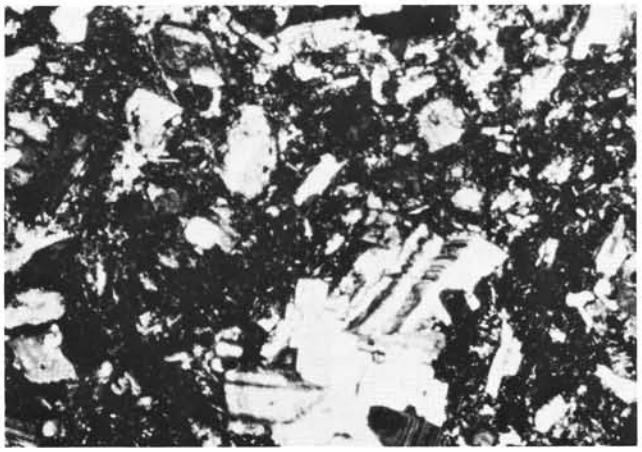


Figure 3. Photomicrograph of porphyritic two-pyroxene basaltic andesite with zoned plagioclase. View is 2 mm across.

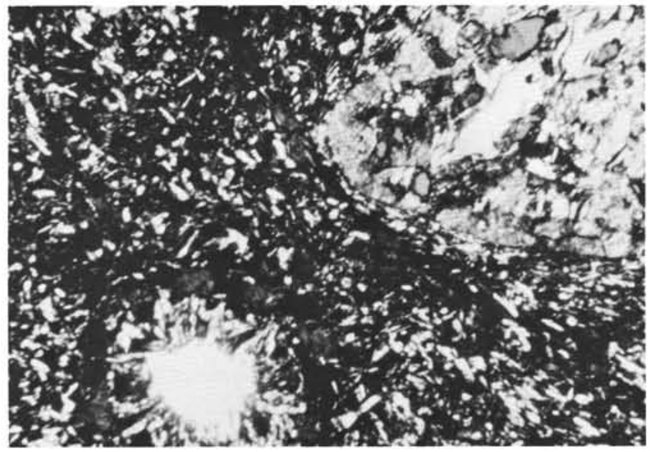


Figure 4. Photomicrograph of nonporphyritic basaltic andesite with quartz crystal showing augite reaction rim. View is 2 mm across.

and, unlike the earlier porphyritic lavas, must have been fairly fluid to be so widespread and thin. It is a fine-grained pilotaxitic felsic andesite with a trace of spongy plagioclase phenocrysts and embayed quartz crystals set in a matrix of plagioclase (An_{49}), augite, and minor glass.

The next of these nonporphyritic andesite flows, an olivine-bearing andesite, is probably related to the intrusion on the west side of John Day Gulch (E½ sec. 12, T. 10 S., R. 19 E.) and is a fine-grained, platy, pilotaxitic andesite with sparse phenocrysts of plagioclase, minor hypersthene, augite, and nontronized olivine in a matrix of plagioclase (An_{48}), augite, magnetite, and minor glass. Identifying features of this unit are nontronized olivines and the small but abundant augite phenocrysts. The third nonporphyritic andesite flow lacks pyroxene phenocrysts and contains more quartz with reaction rims of augite. The uppermost of the four flows is a more felsic andesite with fresh hypersthene and ferric augite phenocrysts.

The three units that stratigraphically overlie the nonporphyritic flows are similar to units that underlie the nonporphyritic units. One of these three units, a more porphyritic andesite that is 110 ft thick, was extruded into the upper sedimentary unit. The uppermost of these three units is subporphyritic basaltic andesite composed of phenocrysts of plagioclase, augite, and hypersthene in a matrix of plagioclase (An_{40}), augite, minor orthopyroxene, and magnetite.

Overlying this entire lower portion of the Clarno Formation is a thick saprolite that represents an ancient soil horizon (Waters and others, 1951) and forms a popcornlike surface on the tilted lower Clarno rocks. Although locally there are other saprolites in the Clarno Formation, the 10-20-ft thickness and the overlying horizontal beds were used to define this particular unit.

UPPER PORTION OF THE CLARNO FORMATION

The division of the Clarno Formation into upper and lower parts is based on the presence of the thick saprolite and angular discordance. The saprolite has been recognized in the Mitchell area (Oles and Enlows, 1971), in the Horse Heaven area (Waters and others, 1951; Swanson and Robinson, 1968), and in the Ashwood area (Peck, 1964). Horizontally bedded volcanic rocks (basaltic andesite, andesite, rhyolite tuff) lie on top of the saprolite. The petrographic similarity of these rocks to lower Clarno volcanic rocks, the 41-m.y. age on an upper Clarno flow (Swanson and Robinson, 1968), and the lack of the recognized welded tuffs that form the base of the John Day Formation in various places (Peck, 1964; Swanson and Robinson, 1968) argue for the inclusion of this volumetrically small group of lavas in the Clarno Formation.

One of the upper Clarno units, a fresh, 100-ft-thick, pilotaxitic basaltic andesite, forms a ridge crest on the saprolite. Olivine phenocrysts are commonly triangular skeletal crystals. The groundmass contains both augite and hypersthene, minor magnetite, and plagioclase (An_{54}).

The most notable upper Clarno event was a huge outwelling of a hornblende andesite dome that forms Wagner Mountain (E½ sec. 10 and all of sec. 11, T. 9 S., R. 19 E.). The eastern margin of the dome has nearly vertical 400-ft-long columnar joints. Phenocrysts in this andesite include oxidized hornblende, hypersthene, and plagioclase (zoned and twinned, with albitic rims).

The uppermost Clarno unit is a 60-ft-thick, nonporphyritic basaltic andesite with a trace of hypersthene and plagioclase phenocrysts. It and the hornblende andesite are the only units with extensive columnar joints.

GENERAL PETROLOGY OF THE CLARNO FORMATION

Except for a few basalts, the flows in this study are either andesites or basaltic andesites. Ignoring the late-stage hornblende andesites for the moment, we can identify two groups of petrographically distinct basaltic andesite lavas (Table 2). The first group contains highly porphyritic plagioclase-clinopyroxene-orthopyroxene rocks. The second group includes the nonporphyritic andesites containing only resorbed quartz and plagioclase crystals and sparse phenocrysts of olivine.

Subhedral to euhedral andesine to labradorite plagioclase crystals 1-5 mm in diameter are the most common phenocrysts in the porphyritic rocks. The most distinguishing feature of the plagioclase is the presence of numerous thin zones, some of which are normal, others oscillatory. Taylor (1960) argued that these zones are responses in a shallow melt to surface eruptions that caused rapid pressure changes. An alternative explanation is that zoning and related resorption features are caused by crystallization of a hydrous melt in which the escape of water at temperatures below the anhydrous liquidus but above the liquidus for that water content forces crystallization (Ringwood, 1975). Repetition of these conditions would lead to the zones.

In the porphyritic lavas, the next two common pheno-

Table 2. *Modal analyses of the three main petrographic Clarno lava types.*

Component	Porphyritic andesite* (%)	Nonporphyritic andesite* (%)	Hornblende andesite** (%)
Phenocrysts			
Plagioclase	26	4	5
Clinopyroxene	3	1	–
Orthopyroxene	9	Tr***	–
Hornblende	–	–	8
Olivine	–	Tr***	–
Quartz	–	1	–
Groundmass			
Plagioclase	47	58	71
Clinopyroxene	7	30	1
Orthopyroxene	1	Tr***	–
Hornblende	–	–	15
Magnetite	7	6	–
Total	100	100	100

* Average of six analyses.
** One analysis.
*** Tr = Trace.

Table 3. *Chemical analyses of the three main petrographic Clarno lava types.*

	Porphyritic andesite*	Nonporphyritic andesite*	Hornblende andesite**
	(wt. %)	(wt. %)	(wt. %)
SiO_2	60.8	61.3	63.3
Al_2O_3	17.3	16.4	17.4
Fe_2O_3	5.9	6.5	5.0
MgO	3.1	2.9	1.9
CaO	5.4	5.8	4.8
Na_2O	3.9	3.3	4.0
K_2O	1.4	1.8	1.9
TiO_2	1.0	.9	.7
Total	98.8	98.9	99.0
	(ppm)	(ppm)	(ppm)
Rb	20.1	42.3	35.5
Sr	474.4	207.1	369.7
Y	11.0	21.0	11.7
Zr	114.8	120.6	97.2
Nb	9.8	11.1	8.7
Ni	32.7	28.1	11.9

* Average of six analyses.
** One analysis.

crysts are fresh, infrequently twinned augite and laths of orthopyroxene, generally hypersthene, replaced by biotite or chlorite. The groundmass consists largely of albite-twinned plagioclase laths (about An_{45}) in flow alignment.

One possible explanation for the texture of the porphyritic lavas could be the shallow emplacement of a magma chamber which was tapped by frequent eruptions during crystallization. As the lavas themselves show no vertical textural or chemical variations, either typical processes of shallow chambers were not operative or the magmas were not derived in this manner.

Alternatively, under hydrous conditions, plagioclase and the two pyroxenes crystallize together over a much narrower temperature interval. Thus, the presence of these three phenocrysts and the zoned feldspar could indicate that the porphyritic lavas were derived from an initially hydrous andesite melt which lost water on rising from some depth.

The nonporphyritic lavas are very similar chemically to the porphyritic rocks (Table 3). Their similarity and proximity in time and space suggest that they had a common source. The key feature of the nonporphyritic lavas is the presence of resorbed quartz phenocrysts. The quartz is clear and occurs as embayed rounded crystals with reaction rims of tiny augites. Quartz has been noted in the volcanic rocks of many island arcs and continental margins across the world (Carmichael and others, 1974; Ringwood, 1975), so its presence here is taken to be primary, not xenocrystic.

The lava probably originated at great depth as a superheated liquid (shown by lack of phenocrysts) and rose rapidly enough so that the ascent was adiabatic. In Marsh and Carmichael's (1974) model, the conditions for formation of such a lava by partial melting of quartz eclogite at the Benioff zone are fairly restricted; consequently, a major outpouring of quartz-bearing basaltic andesite may well represent one time-equivalent event. This relation is particularly suitable to the Clarno Formation, where most stratigraphic columns include nonporphyritic quartz-bearing lavas that apparently occurred during one short span of time (Merriam, 1901; Wilkinson, 1932; Waters and others, 1951; Wagner, 1954; Taylor, 1960; Pigg, 1961; Peck, 1964; Oles and Enlows, 1971; Novitsky-Evans, 1974).

The hornblende andesites present a distinct problem. The role of amphibole in andesite generation has been discussed by several authors (Carmichael and others, 1974; Allen and others, 1975; Ringwood, 1975). The major difficulty in applying present models to the origin of amphibole in the Clarno lavas is the requirement of an extremely shallow Benioff zone (less than 60-80 km). The chemistry of the lavas indicates that there may have been a change in position of the trench or dip of the subduction zone that could account for a change from quartz eclogite melting (nonporphyritic lavas) to a much shallower amphibolite melting. Most of the mudflows in the area are associated with hornblende intrusives; thus, the presence of water may be important in explaining these lavas.

CLARNO SUBDUCTION TECTONICS

Plate-tectonic framework

Dickinson (1979) has placed the Eocene units of the Pacific Northwest within a coherent plate-tectonic framework (Figure 5). Starting in the east, a foreland basin developed across Montana by 65 m.y. ago. Local uplifts and basins were forming throughout Wyoming. The Challis Arc swept westward from Idaho and Montana across central Oregon between 65 and 40 m.y. ago, resulting in Clarno volcanism. To the west, a seamount province (Siletz River and Crescent Formations) that was not originally a part of the North American plate was underthrust and accreted onto the continent as part of a subduction complex. Finally, during Clarno times, a forearc basin developed on top of the seamount province, creating the present-day Oregon coast (Tyee, Nestucca, Cowlitz, and other formations). The Clarno Formation was probably erupted onto the edge of the Eocene continental margin.

Experimental work on the generation of andesitic magmas has placed some limits on the temperature and pressure under which lava can be generated. Theoretical work on the thermal regimes of subduction zones has resulted in a variety of models of temperature versus depth in the subduction region. To hypothesize a subduction origin for a given magma, it is necessary to show that the lavas could have been

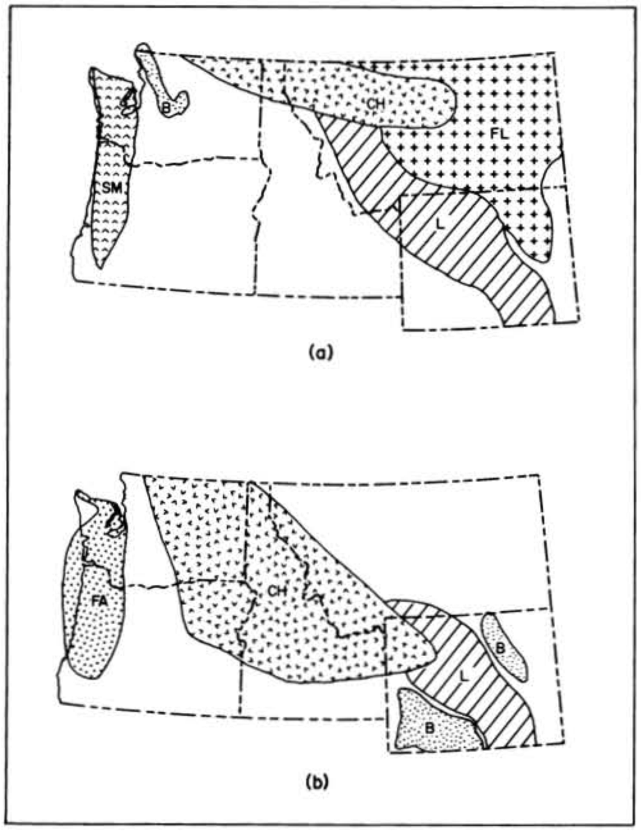


Figure 5. Paleotectonic map of the (a) Paleocene (60 m.y.) and (b) Eocene (45 m.y.) from Dickinson (1979). CH = Challis Arc; FA = Forearc Basin; SM = Seamount Province; B = Basin; L = Laramide Orogeny; FL = Foreland Basin.

melts either on the plate surface or nearby in the overlying mantle. In this study, thermal models from the literature were modified to fit the specific conditions of Clarno time.

Geometry of the Clarno-time plate system

The framework for plate tectonics in the Pacific Northwest was described by Atwater (1970) and augmented by Carlson (1976). In Eocene times, the subduction of the northeastern Pacific Farallon Plate under the North American Plate was presumably the cause of Clarno volcanism. The location of the associated trench has never been precisely determined because of later deposition. However, Simpson and Cox (1977) presented evidence that the coastal seamount province (Siletz River Volcanics) was rotated into its present position clockwise, possibly about a pivot at its southern end, which would suggest that the location of the trench was very close to the location of the present-day Willamette Valley.

Several episodes of Cenozoic sea-floor spreading with different plate motions have been distinguished (Carlson, 1976). Two episodes, one ending at about 42-44 m.y. ago and the second beginning at that time, are relevant to the Clarno. Before that time, plate convergence in the Northwest was oblique at the extremely rapid rate of 14 cm/yr (Carlson, 1976). This convergence may account for the northwest-southeast compression observed in Clarno rocks (Taylor, 1977). After that time, convergence was perpendicular at a rate of 6 cm/yr (Carlson, 1976). These changes in angle and rate of convergence can be correlated with the rearrangement of the Pacific plate system at about 42-44 m.y. ago, as recorded by the break in angle between the Emperor Island chain and the Hawaiian Island trend (Morgan, 1972).

New work by Robinson (1979, personal communication) dates the Clarno Formation between 50 and 40 m.y. Clarno volcanism, then, is a response to the rapid convergence of the plates. The reorganization of the plates marked the cessation of Clarno-type volcanism and the commencement of John Day volcanism. Because the changes in plate motion and the changes in volcanism took place so nearly at the same time (allowing for some lag in the response of the subduction system to these changes), a genetic relation between the events is suggested.

It is important to note that the trench was probably located along the Willamette Valley in western Oregon and the normal component of velocity of the subducted plate was approximately 10 cm/yr.

Depth to the Benioff zone

Various K-h diagrams can be used to determine the depth to the Benioff zone (Nielson and Stoiber, 1973). Rogers and Novitsky-Evans (1977) have shown that the Central American or Aleutian continental margin suites may be most similar to the Clarno. Using an overall average value in the Clarno of 0.95 weight percent for K_{55} (weight percent of K_2O at 55 weight percent of SiO_2) and 1.50 weight percent for K_{60} (Noblett, 1979), one gets depths to the subduction zone of about 105 km. The Clarno Formation lies approximately 200-220 km from the postulated trench. The calculated angle of dip of the subduction zone is thus about 30°. For the slightly higher K_{60} values of the nonporphyritic unit, depths were about 120-130 km, with about a 35° dip.

GENERATION OF CLARNO-TYPE ANDESITIC MAGMA

Proposals for the generation of andesitic magma above subduction zones have included fractionation of basaltic magma; direct partial melting of peridotite; interaction of overlying mantle peridotite with melts rising from the subducted slab; partial melting of either amphibolite or quartz eclogite in the diving slab; and contamination of basalt by sialic crust, subducted sediments, or sea water. Two of the above models seem relevant to the andesitic rocks of the Clarno Formation: (1) interaction of an initially hydrous andesitic melt derived from the subducted plate with mantle peridotite, followed by subsequent fractionation (Ringwood, 1975), and (2) partial melting of quartz eclogite.

As discussed above, the mineral assemblage and textures of the porphyritic lavas can be explained more satisfactorily by the rising of a deep-seated hydrous magma than by formation in a shallow magma chamber. If the porphyritic lavas ever occupied a shallow magma chamber, they probably did so as andesitic lava. The low Ni contents and Ni/Co ratios of the Clarno Formation argue against shallow fractionation from basalt, particularly from a high-alumina basalt, which has similar contents of these elements (Taylor and others, 1969). The large decrease in K/Rb values of over 150 from the base to the top of the porphyritic lavas suggests that fractionation of a hydrous phase was involved in these magmas, supporting the argument that they were hydrous at depth (Table 3; see also Noblett, 1979, for details of chemical analyses). It seems likely that these andesites initially formed from melts on a subducted slab and interacted with peridotite on rising. Fractionation from deep-seated basalt along with the loss of water during ascent would be a viable mechanism for explaining the por-

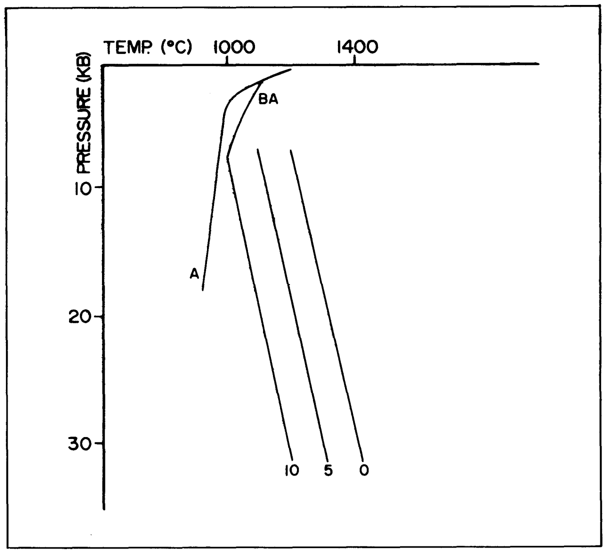


Figure 6. Plot of experimentally determined andesite liquidi. Water-saturated curves for andesite (A) and basaltic andesite (BA) from Nicholls (1974). Curves for andesite with 0, 5, and 10 weight percent water from Green (1972).

phyritic Clarno andesites.

Nicholls (1974) plotted the liquidi of several lavas of andesitic composition (Figure 6). Temperatures of 950°-1,000°C on the surface of the diving slab would be adequate to generate the porphyritic Clarno rocks if they were initially hydrous.

The nonporphyritic quartz-bearing lavas, however, require a different crystallization history. Marsh and Carmichael (1974) and Ringwood (1975) presented many of the arguments relating the presence of quartz to partial melting of anhydrous quartz eclogite.

Marsh and Carmichael (1974) showed that a basaltic andesite magma with less than 0.75 weight percent water at 155-km depth and at 1,400°C would crystallize coesite (which later inverts to quartz). Similarly, Green and Ringwood (1968) found that at 50 kb (about 100 km) 1,400°C would be the liquidus temperature for dry andesite.

Derivation from quartz eclogite appears to explain the textures of the nonporphyritic lavas. With decreasing pressure, quartz is resorbed, and plagioclase lies on the liquidus. The low Zr and Nb contents suggest crustal contamination was not a major process in forming these lavas (Taylor and others, 1969). Nearly constant values of K/Rb in the nonporphyritic units suggest that hydrous phases were not involved in these magmas. Also, the greater depth to the plate for these lavas is below the probable limit of stability for hydrous phases. The element yttrium, which is thought to reflect values of the light rare-earth elements, is enriched in the nonporphyritic rocks relative to the porphyritic andesites (Table 3). This would fit a model of garnet occurring as a residual fractionate. The lack of phenocrysts in these rocks argues against fractionation playing a major role in their development, such as is proposed for the porphyritic lavas. The quartz-bearing basaltic andesites would have to have risen from the surface of the plate without interacting with the mantle peridotite. This implies a rapid adiabatic ascent, which is in agreement with calculations by Marsh (1976).

This review indicates that the Clarno lavas could have originated on the surface of a subducted plate. The early porphyritic lavas would require higher water content, shallower depths, and lower minimum temperatures (about 900°-1,000°C). The later nonporphyritic lavas could have come from deeper than 100 km, from an anhydrous, hotter (1,100°-1,400°C) part of the plate. In the following section, these two sets of conditions are matched with temperatures calculated for the surface of the subducted Farallon Plate in Eocene times.

ORIGIN OF CLARNO VOLCANISM

A thermal model of the subducted plate in Eocene times should approximate the 30° dip and 10-cm/yr velocities as well as incorporate reasonable values of heat sources. Minear and Toksöz (1970) and Oxburgh and Turcotte (1970) presented the best models with a high velocity, while Sydora and others (1978) offered models with 27° and 45° angles of subduction (Figure 7).

Between depths of 100 and 200 km, a plate dipping 30° is about 150°-200°C hotter than one dipping 45°. At 105-km depth, Minear and Toksöz (1970) calculated a temperature of 1,000°C, and Oxburgh and Turcotte (1970) obtained 1,300°C. So the temperature on the plate at the depth where the porphyritic Clarno lavas are thought to have originated was probably between 1,150°C and 1,450°C.

If the plate were 20 km deeper, the temperature would be 75°-125°C greater. This would place the temperature between 1,250°C and 1,550°C, at which point the nonporphyritic lavas could form.

Clarno volcanism, then, can be explained generally in terms of two changes in dip of the subducted slab. The early porphyritic Clarno rocks probably formed about 100 km deep on the surface of a shallowly dipping slab. This is about the greatest depth at which water may still occur on the slab. Rogers and Novitsky-Evans (1977) showed that the crust underlying the Clarno was probably about 20-30 km thick, so a rising hydrous magma could readily have interacted with mantle peridotite and formed the porphyritic rocks.

This was followed by a small increase in dip of the plate (about 5°), which resulted in the anhydrous, hotter conditions needed to form the nonporphyritic lavas. Apparently, the

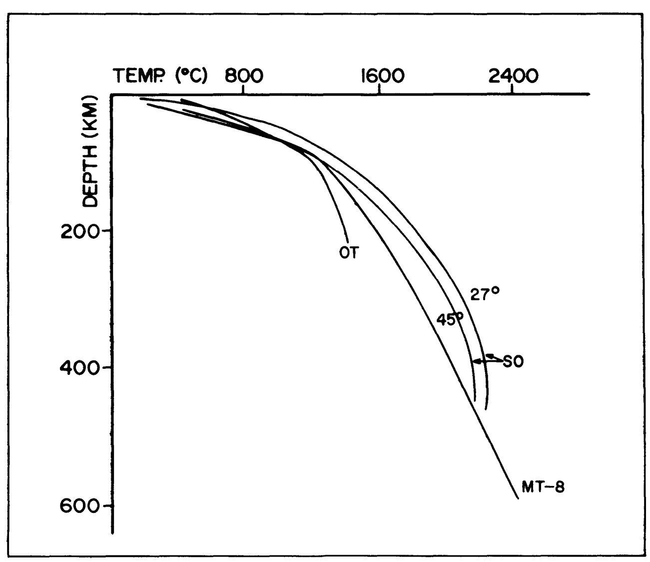


Figure 7. Plot of temperature versus depth on upper surface of slab which is being subducted. Models are from the following sources: OT= Oxburgh and Turcotte (1970); MT-8=Minear and Toksöz (1970), at 8 cm/yr velocity; SO= Sydora and others (1978), at dip angles of 27° and 45°.

plate then readjusted itself to a shallower dip, limiting the nonprophyritic lavas to a brief time interval of extrusion. This shallower dip could lead to hydrous melts again. Such melts could be amphibole-bearing andesites or dacites to rhyolites, as are common in younger Clarno rocks.

With all the variables involved (plate velocity, trench location, all the thermal model parameters, the assumptions involved in estimating the depth of the plate, the experimental data, and the interpretation of the textures of the rocks), this agreement between thermal and experimental models is gratifying. The key variable in the proposed variable dip model is the calculated depth to the Benioff zone. If the plate is much deeper than 100 km, a hydrous melt could not form, and only the partial melting of anhydrous quartz eclogite could occur. It would then be difficult to explain how the early porphyritic or later amphibolitic and silicic lavas might have formed in relation to the subduction system.

CONCLUSIONS

While the stratigraphy of the Clarno Formation in the study area is variable over distances of several miles, the formation can be divided into a few typical lava types. Porphyritic augite-hypersthene basaltic andesites occur throughout the sequence, while nonporphyritic quartz-bearing basaltic andesites occur at one stratigraphic level. This second group of flows is probably equivalent across most other areas of the Clarno Formation. Younger silicic rocks occur in several localities: Horse Heaven (Waters and others, 1951); Mitchell area (Taylor, 1979, personal communication); and Clarno basin (Taylor, 1960). The upper portion of the Clarno, which lies horizontally on a thick saprolite, comprises various thin basalt flows and a hornblende andesite.

The regional geologic setting and its relation to plate-tectonic models of the Pacific Northwest suggest that the Clarno Formation was largely derived from subduction volcanism. The minerals and textures of the lavas as well as the chemical compositions support this hypothesis. For this study, calculated temperatures on the subducted slab of Eocene times were compared with experimentally estimated temperatures to demonstrate that basaltic andesites of the Clarno Formation could have been produced by melting of the subducted slab. The proposed model for generating Clarno rocks suggests that most of the lavas were generated under hydrous conditions at depths of about 100 km. One brief change in the dip of the subducting plate can explain the origin of the nonporphyritic lavas. The key conclusion of interest to Clarno stratigraphy is that the nonporphyritic quartz-bearing lavas were extruded in one short pulse and probably could be correlated across the Clarno as a time horizon.

Certainly, a great deal more work is needed on the Clarno Formation if its origin is to be clarified. The quartz-bearing unit should be traced to see how widespread it is. If alteration has not completely obscured the patterns of distribution of rare-earth elements, such data would be helpful in determining whether partial melting of a quartz eclogite is a possible origin. More radiometric ages and further paleomagnetic data would be useful in improving the tectonic models.

ACKNOWLEDGMENTS

This paper summarizes work done during the summers of 1976-1978 for a doctoral dissertation completed in 1979 (Noblett, 1979). Field mapping and petrography were greatly assisted by Robert Compton. Conversations with George Walker, Don Swanson, and Paul Robinson were instrumental to my understanding of the Clarno Formation.

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Mount St. Helens post-eruption map available

A new post-eruption map of Mount St. Helens and vicinity that includes color photographs of the major eruption and shows the aftereffects of the eruption has been published by the U.S. Geological Survey (USGS), through a cooperative effort with the USDA Forest Service and the Washington State Department of Natural Resources. Copies of the topographic map may be purchased by the public from any of the three agencies.

The 36- × 40-in. topo map is being printed in a first edition of nearly a half million copies, the single largest printing ever made by the USGS. The map shows how the area appears in the wake of the violent eruption of May 18, 1980, and clearly depicts the newly-formed crater and dome, the eruption-impact area, landslide-debris flow, and the mudflows on the Muddy, Toutle and Cowlitz Rivers.

Changes in topography and bodies of water, including Spirit Lake, are readily seen when compared to the earlier USGS pre-eruption special edition "Mount St. Helens and Vicinity" map of April 1980 or the Forest Service map, "Mount St. Helens-Spirit Lake" of 1973.

Presented at a scale of 1:100,000 (1 in. equals about 1.68 mi), the map has been updated from aerial photography taken June 19, 1980. The map denotes land managed by federal and state agencies and includes numerical designations for roads within the Gifford Pinchot National Forest, viewpoints, campgrounds, picnic areas, visitor centers, and points of interest.

On the reverse side of the map, the Forest Service has presented text and color photographs providing a narrative of recent Mount St. Helens volcanic activities. Included are before and after panoramic views of the devastated area, history and legends of the mountain and a glossary of volcanic terms.

In the joint federal-state effort, USGS cartographers at the Western Mapping Center, Menlo Park, Calif., mapped the new topographical features; the Washington State Department of Natural Resources delineated the eruption impact and mudflow areas and, with the Forest Service, depicted land management patterns.

Maps may be purchased by mail from the Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, Colo. 80225, as well as from most USGS map dealers. Orders by mail to the USGS Branch of Distribution must specify map title ("Mount St. Helens and Vicinity, March 1981") and include check or money order payable to the U.S. Geological Survey.

Copies of the map also may be obtained over the counter or by mail from the Forest Supervisor, Gifford Pinchot National Forest, 500 West 12th St., Vancouver, Wash. 98660. Mail orders must include check or money order ($1.00 per map) made payable to the USDA Forest Service.

Maps also are available from the Washington State Department of Natural Resources, Resources Inventory Section, Olympia, Wash. 98504. Orders by mail should include check or money order payable to Department of Natural Resources. □

ABSTRACTS

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

THE GEOLOGY AND GEOCHEMISTRY OF THE NORTH FORK STOCK, NORTHEASTERN OREGON, by David Joseph Matty (M.S., Portland State University, 1980)

The North Fork stock is a composite intrusive body of Late Jurassic-Early Cretaceous age which crops out in the Blue Mountains of northeastern Oregon. The upper 600 m of the intrusion are exposed over an area of approximately 36 km² along the canyon walls of the North Fork of the John Day River in Grant and Umatilla counties. The stock intrudes metasediments, metavolcanics, and metagabbros associated with the Permian-Triassic Elkhorn Ridge Argillite. Contact metamorphism of the Elkhorn Ridge Argillite is developed to the hornblende-hornfels facies throughout most of the exposed area of this unit in the study area. The contact aureole of the North Fork stock extends away from the intrusive margins and ultimately grades into regionally metamorphosed greenschist- and amphibolite-facies rocks. The metamorphic rocks exhibit a pronounced regional trend of foliation which is disrupted where it intersects intrusive contacts at steep angles.

The North Fork stock comprises at least 21 mineralogically, texturally, or geochemically distinct units which range in composition from gabbro to quartz-rich granitoid. The earliest intrusive phase is represented by hornblende gabbro, which occurs as xenoliths within younger quartz diorite. The bulk of the intrusion is represented by the concentrically zoned North Fork tonalite-granodiorite, which ranges in composition from biotite-hornblende tonalite to biotite-hornblende quartz diorite to hornblende-bearing, biotite granodiorite. Three mineralogically equivalent granodiorite bodies exist. Late-stage granitic dikes and minor stocks cut the tonalite-granodiorite, as do lamprophyre, quartz diorite, granodiorite, mafic, and basalt dikes. A concentrically zoned lamprophyre body comprising lamprophyre, orbicular lamprophyric tonalite, and hornblende tonalite pegmatite is spatially associated with the North Fork intrusion. The North Fork stock and its surrounding country rocks are unconformably overlain by younger rocks of the Clarno Formation and the Columbia River Basalt Group.

Xenoliths derived from wall rocks and from earlier intrusives are common in the tonalite-granodiorite rocks, which suggests stoping to be the dominant emplacement mechanism at the present level of exposure. Evidence for forceful emplacement also exists, thus implying that the stock was at least partially emplaced by this mechanism. Field, petrographic, and geochemical evidence support the interpretation that the North Fork stock is a post-tectonically emplaced, imperfectly exposed, stock-shaped mass which extends to the south of present exposures beneath a thin cover of metamorphic rocks.

Geochemical analyses of selected samples indicate that rocks of the stock may be characterized by their respective concentrations of Fe, Na, and K, and also by their REE profiles. Concentrations of Co, Sc, and Cr may also be used to distinguish different units of the stock. Observed geochemical trends in the North Fork stock indicate that the composite nature of the stock is a result of both multiple magmatic injections and of magmatic differentiation due to fractional crystallization. The hornblende gabbro is the most primitive rock and is characterized by slightly LREE enriched, subchondritic REE profiles at ~20 X chondrite. Progressing inward from the main intrusive margin, the REE are progressively enriched, with subsequent development of a negative Eu anomaly and distinct LREE enrichment. Accompanying these changes are decreasing concentrations of the transition metals (Fe, Sc, Co, and Cr) and generally increasing concentrations of the LIL elements. Such trends are generally compatible with crystal fractionation models. Observed variations in the tonalite-granodiorite series may theoretically be explained by equilibrium fractionation of a hornblende-plagioclase assemblage, while minor crossovers in REE profiles may be in part due to minor fractionation of accessory minerals. Geochemical considerations preclude derivation of the tonalite-granodiorite by fractionation of the more primitive hornblende gabbro magma.

STRATIGRAPHY AND SEDIMENTARY PETROLOGY OF THE NORTHWEST QUARTER OF THE DUTCHMAN BUTTE QUANDRANGLE, SOUTHWEST OREGON, by Thomas Edward Koler (M.S., Portland State University, 1980)

The study area lies in southwest Douglas County 5 km south from Camas Valley and is accessible by State Highway 42. The purpose of the study was to map the geology at a 1:31,250 scale, determine the stratigraphy, study the petrology of the formations, and determine the provenance within a tectonic setting.

Structural features that control the map pattern of the northwest quarter of the Dutchman Butte quadrangle are a syncline and anticline which trend to the northwest. Both folded structures are truncated by the east-trending Canyonville fault zone within the area mapped. The last movement in the fault zone occurred in the middle Eocene and was down to the north.

All of the rocks within the study area, with the exception of a few minor serpentinite bodies, are sedimentary. Clast composition of the coarse-grained sedimentary rocks is a varied composition of basaltic andesite, andesite, quartzite, phyllite, chert, mudstone, sandstone, and conglomerate. Grain compositions of the fine-grained sedimentary rocks reflect a similar source.

The oldest formations within the study area are the Late Jurassic Dothan Formation and the Late Jurassic to Early Cretaceous Riddle and Days Creek Formations of the Myrtle Group. These formations are within and to the south of the Canyonville fault zone. The Eocene Roseburg, Lookingglass, and Flournoy Formations are overlying the Mesozoic formations. Stratigraphic thickness of the pre-Tertiary formations was not determined due to severe structural deformation of the units; however, an estimation of 1 km or more was made. Thickness for the Eocene formations was calculated from measured sections to be at least 900 m. Primary sedimentary structures including rip-ups, flute casts, trough sets, cross-bedding, ripple marks, and channel scour and fill are common throughout the study area. These structures, when analyzed in conjunction with the geometry of the planar and lenticular bedding, are interpreted to have been formed within a prodeltaic to deltaic depositional environment on a continental shelf or slope or in a tectonic basin. Paleocurrent directions were from the south-southwest and southeast. Composition of the sedimentary rocks indicates a volcanic-arc source, possibly the Rogue Formation which lies to the south of the study area. Paleocurrents of south-southwest and basaltic rock fragments in some outcrops indicate a second possible source from the Mt. Bolivar igneous complex in the adjacent Bone Mountain quadrangle. □

BLM warns gold miners to beware of invalid claims

Fradulent sales of invalid and other worthless mining claims located on federal land in the Northwest are costing purchasers thousands of dollars each year, according to Gary Rundell, realty specialist for the Bureau of Land Management (BLM).

Selling a claim is legal regardless of its mineral value. Fraud enters when a mining claimant knowingly sells an invalid claim or intentionally exaggerates its mineral worth.

Most often, the sale of such claims is tied to an illegal occupancy of the site. The 1872 Mining Law allows claimants who are actively mining to reside on a claim only if it is necessary for mineral extraction. Yet many people abuse this law by constructing residences on claims under the guise of prospecting or mining.

When illegal occupancy is suspected, BLM conducts validity examinations to determine if there are sufficient quantities of valuable minerals on the claim. If not, steps will be taken to invalidate the claim and remove the occupants and the buildings.

It's at this point, when the government is seeking to remove the illegal occupants, that residents sometimes begin to look for an unsuspecting buyer.

"They sell out when they see the ax coming down," Rundell explained. "Senior citizens often buy these claims after being told by the original claimant that they can retire on the property. Some people lose their life's savings on invalid claims."

Each year, 10-15 cases of selling invalid claims are reported to BLM, and that is only a portion of the total, Rundell said. Prices for the claims commonly range from $1,000 to $20,000. Purchasers often are younger city dwellers or out-of-state residents looking for a retreat. Many of the buyers are retired and are hoping to supplement their income by mining.

A typical fraudulent sale occurred in 1979 near Durkee, Oregon. Lands along the Burnt River had been withdrawn from mining in the early 1960's because of a proposed dam construction.

Yet mining claims were filed on the land, and a residence built in the early 1970's. The claim was declared null and void by BLM and removal procedures started.

Unknown to BLM, the claimant began marketing his claim and soon sold it to an 83-year-old man for $17,000.

In such cases, BLM will consider the hardships imposed on the purchaser and will often try to work out a permit or rental agreement. But the objective is still to eventually terminate the occupancy, Rundell said.

Private citizens are not the only group affected by the fraudulent sales. Rundell said a California county paid for a road right-of-way across 13 mining claims, all of which were invalid.

"We never get inquiries from counties, yet they are always buying their way across mining claims," Rundell said. "Often, it's a waste of taxpayer's money."

A TIP OR TWO

Prospective buyers should check out several items at the BLM office nearest the claim, Rundell suggested. Records will show pending trespass actions, the outcome of mineral validity tests, whether the land is open for mining, and if the claim has been declared null and void.

"Look at the present use of the claim. Be especially aware of residential structures on the claims. If there are such structures, the chances are that the claim is on our list awaiting investigation," Rundell said.

With the recent rise of interest in gold mining, there will likely be more claims for sale in the northwest. Those buying a claim on federal land without first checking its status risk disappointment and financial loss.

During the past three years, 23,000 mining claims in Oregon and Washington were filed with the Bureau of Land Management. □

—BLM News Clips

Friends of Mineralogy to meet in September

The seventh annual meeting of the Friends of Mineralogy will be held September 25-27, 1981, at the Holiday Inn, Bellevue, Washington.

Theme of the meeting will be "Silicates." Speakers and their topics include Paul Moore, University of Chicago, "Paragenesis of Silicate Minerals" and "Search for the Lone Pair—New Changes in Mineralogy"; Dick Bideaux, co-author of *Mineralogy of Arizona*, "Copper and Lead-Copper Silicates of Arizona" and "New Silicates from Franklin, New Jersey"; and Al Falster, mineralogist and dealer, "Silicate Minerals of the Alpine Clefts" and "Silicate Minerals of the Wausau Pluton, Wisconsin."

Pre-registration cost of the meeting is $22.50 per person or $10.00 per student. Send registration checks to Bob Smith, c/o Friends of Mineralogy, 7th Annual Symposium, Box 197, Mailroom, Seattle University, Seattle, Washington 98122. For additional information, contact Mike Groben, 1590 Olive Barber Road, Coos Bay, Oregon 97420; phone (503) 269-9032. □

BLM sends $268,628 check to State of Oregon

Oregon received a $268,628 payment from the Bureau of Land Management (BLM) for mineral leasing activities on public land for a six-month period ending March 31. Washington state also received $10,161.

Overall, BLM distributed $168 million to 23 states, an increase of $17 million over the same period last year. With the exception of Alaska, states receive 50 percent of the bonuses, rentals, and royalties collected from mineral leasing activities on federally owned land. Alaska receives a 90-percent share. The funds are used for public purposes designated by the state, giving priority to areas where most mineral production on Federal land occurs.

Highest payments were to Wyoming and New Mexico which received $59 million and $56 million respectively. The payments to Oregon and Washington should increase in the future with the growing activity in oil, gas, and geothermal exploration in the Northwest. □

Mining and mail

by Lewis A. McArthur. Reprinted from The Ore Bin, *1946, v. 8, no. 9, p. 66*

In nearly a century of Oregon postal history, the influence of miners, geologists, and metallurgists has been sufficient to produce almost eighty post office names. A list of them by counties is given below.

There are possibly some omissions in the list. The writer strained a point when he listed Rock Creek, Soap Creek, and Arock. These names have no particular mineral significance, but it is probably better to have them in the record than to leave them out. The fact that Jasper was named for Jasper Hills, a prominent Lane County resident, does not detract from the general interest of the name. Oretown in Tillamook County is a synthetic name with Oregon as a base, so readers need not go there with pick and pan.

Post office names only are included in this list.

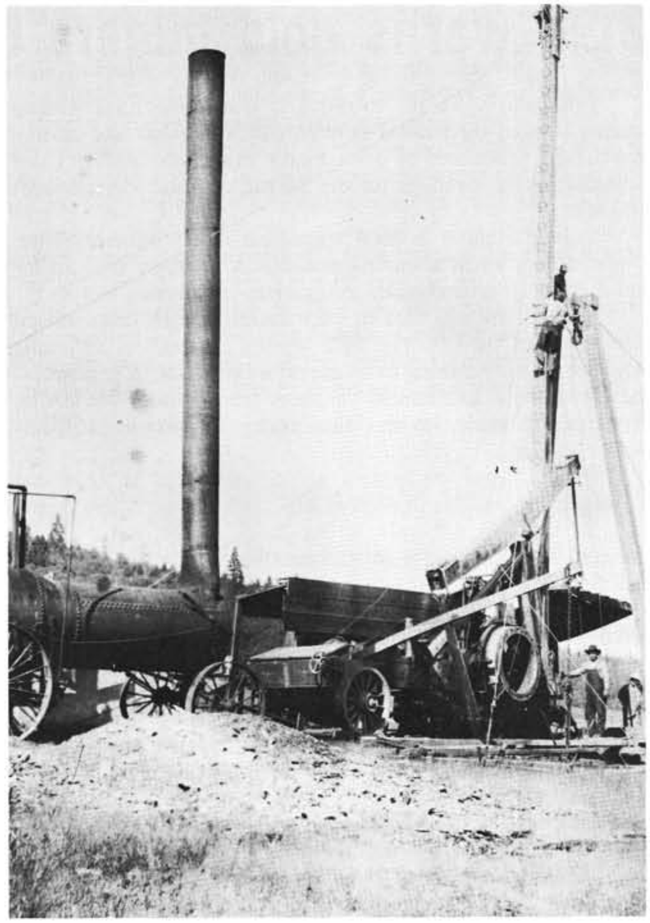
Baker County: Chloride, Copperfield, Gem, Gypsum, Lime, Rock Creek.
Benton County: Soap Creek.
Clackamas County: Stone, Sandy.
Columbia County: Pebble.
Coos County: Coaledo, Gravel Ford.
Crook County: Silver Wells.
Curry County: Gold Beach, Sandstone.
Deschutes County: Crater, Lava.
Douglas County: Diamond Lake, Nugget, Ruby, Sulphur Springs.
Gilliam County: Alkali, Gumbo, Lone Rock, Oasis, Rock Creek, Rockville.
Grant County: Court Rock, Galena, Granite.
Harney County: Diamond.
Hood River County: Shell Rock.
Jackson County: Agate, Asbestos, Copper, Gold Hill, Gold River, Prospect, Rock Point, Soda Springs.
Jefferson County: Opal City, Warm Springs.
Josephine County: Golden, Granite Hill, Placer, Slate Creek.
Klamath County: Crystal.
Lake County: Hot Springs, Quartz Mountain, Silver Lake.
Lane County: Jasper, Mineral, Natron, Salt Springs.
Lincoln County: Agate Beach.
Linn County: Diamond, Diamond Hill, Lower Soda, Rock Creek, Soda Springs, Soda Stone, Sodaville.
Malheur County: Arock, Ironside, Rockville, Stone.
Marion County: Argenti, Pyrite, Silver Creek, Silverton.
Morrow County: Salineville.
Multnomah County: Sandy.
Polk County: Black Rock, Salt Creek.
Tillamook County: Oretown.
Union County: Hot Lake, Medical Springs.
Wallowa County: Copper.
Wheeler County: Barite. □

What comprises a barrel of crude oil?

Each barrel of crude oil produces the following: gasoline, 46.2 percent; fuel oil, 28.6 percent; petrochemicals, 10.1 percent, jet fuel, 7.4 percent; asphalt, 4.0 percent; kerosene, 2.1 percent, and lubricants, 1.6 percent.

Some of the petrochemical products made from a barrel of crude oil include all plastics, nylon, rayon, polyester, cosmetics, detergents, paint, drugs, and tires. □

—Society of Petroleum Engineers



One of Oregon's first oil rigs, Sutherlin Valley, Douglas County. The well was unsuccessfully drilled for oil to a depth of 2,500 ft on the Oakland-Sutherlin anticline. It did, however, encounter considerable salt water. Photo taken by Walton Gray Hughes, August 12, 1909, and given to the Oregon Department of Geology and Mineral Industries by James G. Osborne, Jr.

New edition of 'Geology of Oregon' published

Geology of Oregon, by E.M. Baldwin, now in its third printing, is an excellent review of the subject. The text clearly describes those rock formations and geologic processes that have resulted in the numerous geologic features of the state. Many outstanding photographs and diagrams vividly present a pictorial review of crustal features of the earth.

This book is a must—a well illustrated and referenced presentation on rock formations and geologic processes, which together tell the historical geology story of the state of Oregon.

Published by Kendall/Hunt Publishing Company of Dubuque, Iowa, *Geology of Oregon* is available at most local bookstores and sells for $11.95. □

—Weldon W. Rau, in the Washington Geologic Newsletter, *published by the State of Washington Division of Geology and Earth Resources*

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COVER PHOTO

Mafic dike of John Day Formation cutting Cretaceous marine mudstones of the Hudspeth Formation along Gable Creek in the Mitchell quadrangle, Oregon. The article beginning on the next page discusses these dikes.

New index of Oregon topo maps available from USGS

A new index showing areas of the State of Oregon covered by 1,091 published topographic maps is now available upon request from the U.S. Geological Survey (USGS).

By showing the shape and elevation of the terrain and delineating a wide range of natural and manmade features, standard USGS topographic quadrangle maps are valuable records of the land surface for engineers, scientists, planners, and others concerned with the nation's resources. The maps also are popular with hikers, hunters, campers, and other open-air enthusiasts as "silent guides" to the outdoors. The USGS annually distributes more than 10.5 million copies of its 45,000 published "topo" maps.

The Oregon index includes a map of the state showing areas covered by each of the available 7½-minute and 15-minute quadrangle maps. The text on the back of the index lists other maps of Oregon published by the Survey, such as maps of the entire state, rivers and creeks, reservoirs and damsites, and Crater Lake National Park.

More than 85 percent of Oregon has now been covered by quadrangle maps. The 7½-minute maps are at a scale of 1:24,000 (1 in. equals 2,000 ft) and the 15-minute quadrangle maps are at a scale of 1:62,500 (1 in. equals about 1 mi).

USGS-published maps of Oregon are deposited and available for inspection at nine reference libraries in the state—in Ashland, Bend, Corvallis, Eugene, Klamath Falls, La Grande, Monmouth, Portland, and Salem. The index also lists commercial outlets in Oregon, California, Idaho and Washington where many of the maps may be purchased, including the Portland office of the Oregon Department of Geology and Mineral Industries.

Copies of the "Index to Topographic Maps of Oregon" are available free from USGS Public Inquiries Offices in Menlo Park, Calif. (Building 3, 345 Middlefield Rd.); San Francisco (504 Custom House, 555 Battery St.); Los Angeles (7638 Federal Building, 300 North Los Angeles St.) and Spokane, Wash. (678 U.S. Court House, West 920 Riverside Ave.). □

Mine reclamation fees increase

The 1981 Oregon Legislative Assembly passed House Bill 2220 increasing the fees (provided in ORS 517.800) for mining reclamation. The bill was signed by the Governor and became effective upon signature July 2, 1981.

The application fee for a new site is $390, and the annual renewal fee is $290. The increase is designed to maintain the self-sufficiency of the Mined Land Reclamation Program through the 1981-1983 biennium. This program, intended to restore surface mined land to a continuing useful purpose, is 90 percent funded by the industry it regulates.

The new fees are now effective for all new mining site applications. Renewal fees are effective August 1981. □

CONTENTS

A mafic dike system in the vicinity of Mitchell, Oregon, and its bearing on the timing of Clarno-John Day volcanism and early Oligocene deformation in central Oregon

by Edward M. Taylor, Department of Geology, Oregon State University, Corvallis, Oregon 97331

INTRODUCTION

A system of west-northwest-trending basaltic dikes crops out in the vicinity of Mitchell, Oregon. The dikes are exposed best in the central part of the northeast-southwest-trending Mitchell anticline, where they have intruded Cretaceous marine sedimentary rocks of the Gable Creek and Hudspeth Formations. The dikes also have penetrated the overlying volcanic rocks of the Clarno Formation on both limbs of the anticline and were probably associated with basaltic lava flows of the lower John Day Formation. Parts of this dike system appear on a published geologic map of the Mitchell quadrangle and have been designated "Airport dikes," "Nelson Creek dikes," and "Keyes Creek dikes" (Oles and Enlows, 1971).

The mafic dike system has been traced over an area approximately 9 mi long and 2 mi wide in which the dikes are arranged in groups of subparallel segments (Figure 1). Individual segments range in length from 1 mi to a few tens of feet and are commonly offset from each other along trend. Adjacent segments locally taper to thin edges at their extremities, or they are joined, nearly at right angles, by short connective dikes. Most of the dike segments are 15-20 ft wide; their width at a few localities where bulbous protrusions extend into incompetent rocks is as much as 110 ft. In contrast, some dikes apparently were unable to invade competent rock; they terminate or bifurcate just below thick resistant strata or preexistent sills.

Elongate depressions are produced by erosion of dikes that cut resistant strata (Figure 2). Elsewhere, as in soft mudstones of the Hudspeth Formation, low ridges mark the positions of dikes (Figure 3). Volcanic mudflow deposits of the

Figure 1. Distribution of high Fe-Ti tholeiitic basalt dikes of late Oligocene age in the vicinity of Mitchell, Oregon. Heavy solid lines represent dike outcrops; dotted lines represent inferred positions of covered dikes.

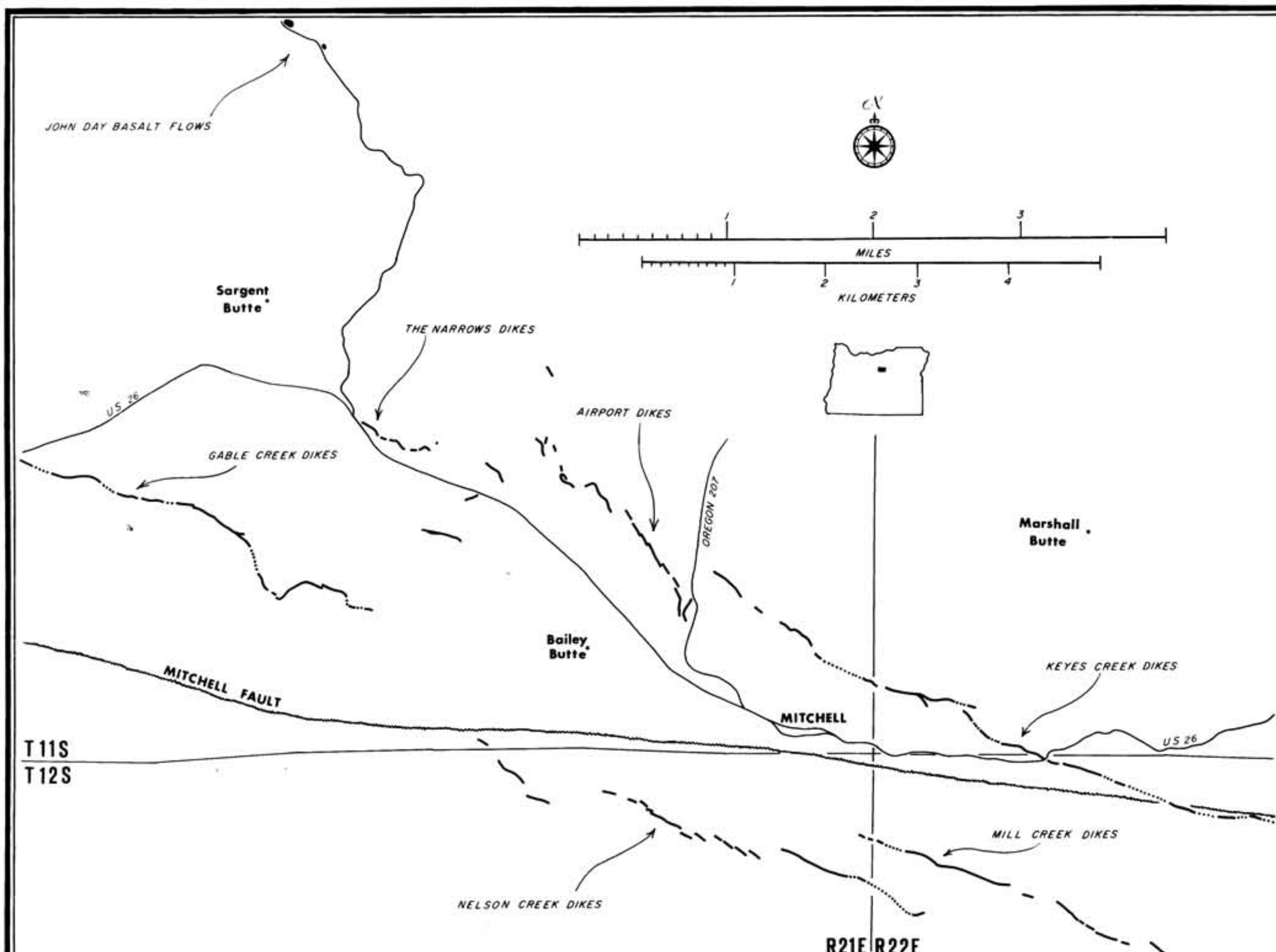

Figure 2. Mafic dike in negative relief. Country rock is erosionally resistant conglomerate of the Gable Creek Formation, 3.8 mi west of Mitchell.

Clarno Formation have been so indurated in close proximity to the dikes that double walls of erosionally resistant mudflow can be found standing in relief along dike margins.

The margins of dikes consist of very fine-grained, black, devitrified glass in a chilled zone up to 2 ft wide. Dike interiors are gray where fresh, uniformly coarse grained, and commonly display crude columnar jointing (Figure 4). Weathering of dike rocks is always more advanced in the interior than at the margins and produces a dark-brown, ferruginous soil.

PETROGRAPHY

In the dike margins, thin tablets of plagioclase (An_{55}) make up 3-4 percent of the rock and are never more than 0.5 mm long. They are surrounded by grains of pyroxene and magnetite approximately 0.001 mm in diameter which form a very fine-grained intergranular texture with microlites of plagioclase. Thin films of brown glass still exist in the freshest samples. A green isotropic clay mineral, probably a complex chlorite interlayered with other phyllosilicates replacing traces of olivine, occurs in euhedral patches up to 0.5 mm in diameter (Figure 5A).

The zone of transition between the fine-grained margins and the coarse-grained interior of dikes is only 7-10 in. wide (Figure 6). Within this zone, elongate crystals of clinopyroxene and plagioclase are suspended in a fine groundmass and become larger and more abundant toward the interior. Near the inner boundary of the transition zone, the groundmass is represented by small, fine-grained patches of late-crystallizing

Figure 3. Mafic dike in positive relief. Country rock is easily eroded mudstone of the Hudspeth Formation, 2.8 mi west of Mitchell.

Figure 4. Columnar jointing in the Keyes Creek dike adjacent to U.S. Highway 26. Hat rests upon contact with volcanic mudflow deposits of the Clarno Formation.

feldspar, largely altered to smectite (Figure 5B).

Wherever the width of dikes exceeds 10-12 ft, the interior is texturally hypidiomorphic-granular, consisting of plagioclase, monoclinic pyroxene, and opaque oxides up to 1.5 mm in length (Figure 5C). Plagioclase of composition An_{50-60} makes up 75 percent of the dike rocks. The pyroxene is a dusky augite with a 2V of 45-48° and commonly constitutes 18-20 percent of the rock. The opaque oxide, which is titanomagnetite in the fine-grained margin, becomes a coarse-grained skeletal and dendritic admixture of ilmenite and magnetite in the interior.

Alteration of dike rocks by deuteric processes and weathering has converted all olivine to green chloritic minerals. In varying degrees, pyroxene is altered to highly birefringent yellow and orange smectite, ilmenite and magnetite are altered to leucoxene and hematite, and plagioclase is replaced by carbonate. In Table 1, the chemical effects of alteration are revealed by the contrast between column 3, an average of two very fresh samples from dike margins, and column 4, an average of seven altered samples from dike interiors. Altered dike rocks have lost Fe and Mg but gained Ca and an unspecified quantity of H_2O and CO_2.

Rocks of the mafic dike system in the Mitchell area are low-alumina tholeiites enriched in Fe and Ti. They are distinct from Mitchell-area basaltic flows and dikes of the Clarno Formation in which the Al, Ca, and Mg content is much greater and the Fe and Ti content is much smaller (Taylor, unpublished data). Major-element composition of the dikes is also distinct from basalts of the Picture Gorge Formation in the Mitchell area because the dikes contain much more Fe and Ti. The closest compositional match to the mafic dike system is

*Table 1. Major-element composition of mafic dikes near Mitchell, Oregon**

	(1)	(2)	(3)	(4)	(5)
SiO_2	51.3	51.8	51.6	52.0	47.74
Al_2O_3	12.8	13.4	13.1	13.7	15.27
FeO	15.6	14.5	15.1	14.1	15.2
CaO	7.8	8.5	8.2	8.6	7.57
MgO	5.4	4.0	4.7	3.5	4.70
K_2O	0.65	0.50	0.60	0.75	1.46
Na_2O	3.1	3.1	3.1	3.0	3.48
TiO_2	3.10	3.00	3.05	3.00	3.33
Total	99.75	98.80	99.45	98.65	98.75

(1) Fresh marginal glass from Keyes Creek dike, 500 ft north of south corner secs. 31 and 32, T. 11 S., R. 22 E.

(2) Fresh marginal glass from east end of Mill Creek dike, 4,400 ft elevation, NW¼ sec. 9, T. 12 S., R. 22 E.

(3) Average of (1) and (2).

(4) Average of seven slightly altered rocks from dike interiors, representing all dike groups.

(5) Basaltic lava from lower John Day Formation, 6 mi northwest of Mitchell, 700 ft west of intersection of secs. 4, 5, 8, and 9, T. 11 S., R. 21 E. Recast H_2O-free from Hay (1962).

* Analyses (1)-(4) by XRF and AAS. Total Fe as FeO. H_2O and CO_2 not included because samples were fused before analysis.

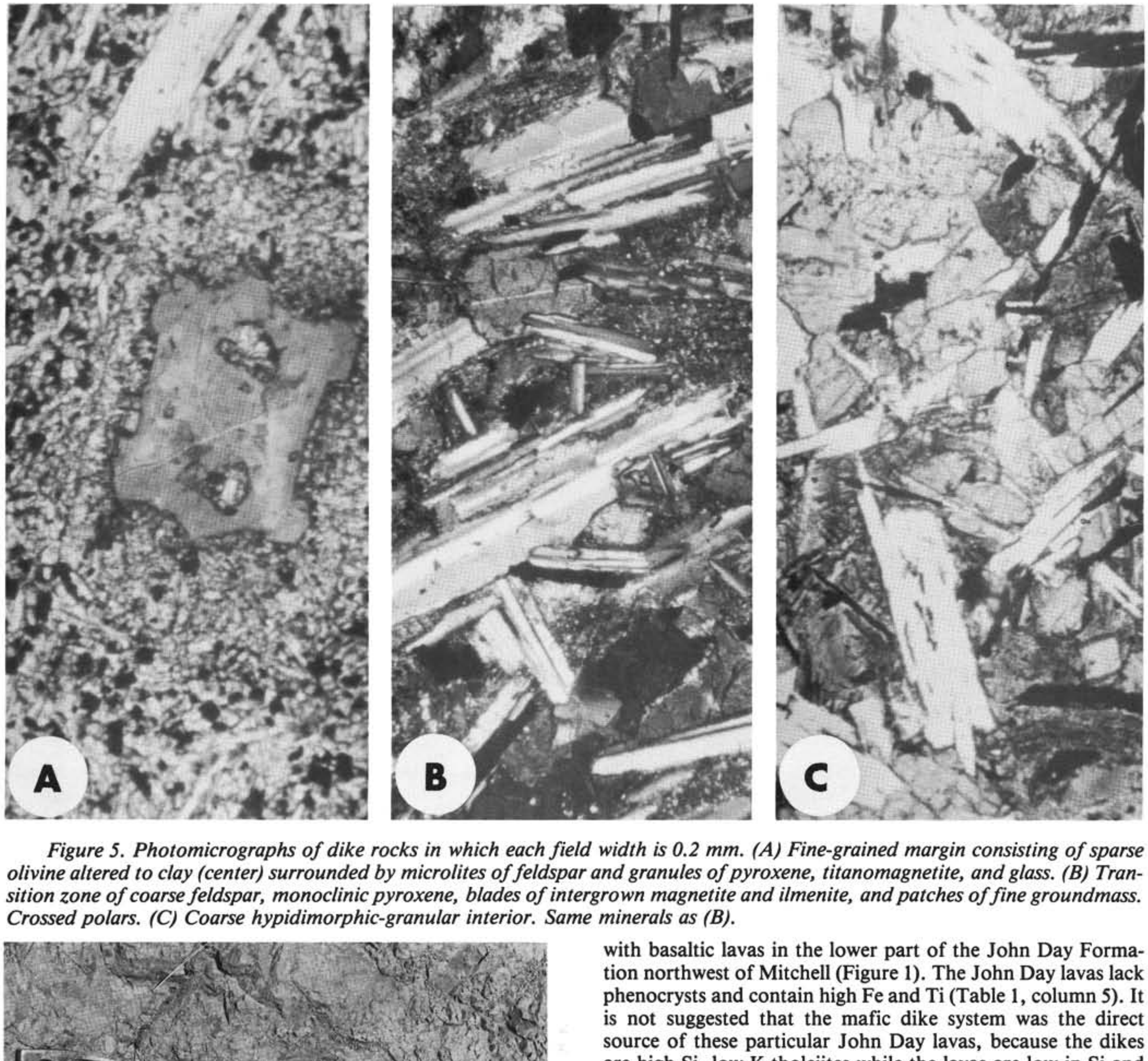

Figure 5. Photomicrographs of dike rocks in which each field width is 0.2 mm. (A) Fine-grained margin consisting of sparse olivine altered to clay (center) surrounded by microlites of feldspar and granules of pyroxene, titanomagnetite, and glass. (B) Transition zone of coarse feldspar, monoclinic pyroxene, blades of intergrown magnetite and ilmenite, and patches of fine groundmass. Crossed polars. (C) Coarse hypidimorphic-granular interior. Same minerals as (B).

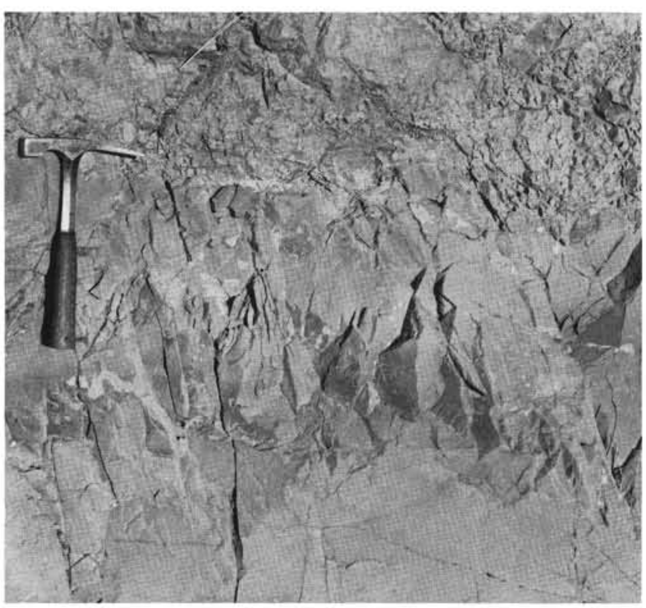

Figure 6. Transition zone from fine-grained, close-fractured margin (below head of hammer) to coarse-grained interior of mafic dike (above head of hammer).

with basaltic lavas in the lower part of the John Day Formation northwest of Mitchell (Figure 1). The John Day lavas lack phenocrysts and contain high Fe and Ti (Table 1, column 5). It is not suggested that the mafic dike system was the direct source of these particular John Day lavas, because the dikes are high-Si, low-K tholeiites while the lavas are low in Si and high in K, transitional to alkali basalts (Robinson, 1969).

CONCLUSIONS AND SPECULATIONS

Emplacement of the dikes

An obvious feature in need of resolution is the rather peculiar distribution of the dikes. Within the overall west-northwest trend, the dikes occur in distinct groups that are successively offset en echelon in a left-lateral sense. For example, Nelson Creek dikes seem to be offset from Mill Creek dikes, and a similar pattern is exhibited by Gable Creek, The Narrows, Airport, and Keyes Creek dikes (Figure 1). On a smaller scale, the same pattern can be seen between the individual offset segments of each dike group.

Although it has been reported that "dikes generally occupy preexiting faults" and some dike segments have been shown on geologic maps to be offset by strike-slip faults (Oles and Enlows, 1971, map and explanation), detailed study of the dikes and surrounding country rock has failed to confirm these relationships. Many faults of varying extent and displacement occur in the vicinity of dikes but not one has been found to be coincident with a dike. Slickensided fractures have been found within dike rocks at two localities; displacement of only a few feet is indicated. Where extremities of dikes are exposed, they are seen to taper to thin edges rather than blunt, faulted terminations. Moreover, adjacent segments often overlap in parallel alignment far beyond the positions of possible cross faults.

The Keyes Creek and Nelson Creek dikes have been described as parts of a single dike that has been offset 22,000 ft by right-lateral slip along the Mitchell fault (Oles and Enlows, 1971, p. 48, 54, 59). This interpretation must be reconsidered, because the eastern 1 mi of the Keyes Creek dike cuts across the Mitchell fault (Figure 1). Segments of the dike lie in the crush zone of the fault and display no evidence of disruption or reorientation. If the Nelson Creek dikes are correctly projected to the Mitchell fault, an offset of 28,000 ft is indicated. This is more than twice the right-lateral displacement of the Mitchell fault, as demonstrated by offset of the axis of the Mitchell anticline (Wilkinson and Oles, 1968). It is my conclusion that the mafic dike system in the Mitchell area has not been significantly displaced by later faulting of any kind. In particular, right-lateral movement along the Mitchell fault preceded dike emplacement.

The dike segments are not randomly located; in both position and orientation their emplacement appears to have been systematically controlled. It is especially significant that the dikes, with one exception, seem to have avoided the trace of the Mitchell fault and many other faults that are parallel to it. What could have localized the dikes? This question can be readily answered if it is assumed that the dikes were emplaced after most of the right-lateral movement had occurred on the Mitchell fault but before the responsible conditions of stress had died out. The magma would have found paths of least resistance along gash fractures at acute angles to the Mitchell fault, while passage of magma into the fault zone itself would have been hindered. Gash fracture control of the dikes was proposed by Oles and Enlows (1971, p. 59), but they also emphasized dike emplacement prior to right-lateral faulting and presumably prior to development of gash fractures.

A new emphasis should be placed upon the nearly equivalent age of the dike system and the Mitchell fault. If a deep-seated body of mafic, nonporphyritic, fluid magma, elongate in a west-northwest direction, was intersected by a zone of right-lateral disruption of the crust along the Mitchell fault, the magma could have penetrated gash fractures and produced the pattern of dikes now seen in the Mitchell area. Indeed, without this combination of tectonic pressures and avenues of escape, the dense magma might never have reached shallow crustal levels or poured over the surface.

Age of the dikes

K-Ar ages of the Nelson Creek dikes and Airport dikes were reported to be 29.4 ± 0.6 and 33.4 ± 1.3 m.y., respectively (Enlows and Parker, 1972). However, the dikes were probably formed at the same time. It is unlikely that, in this small area, many separate magmas of nearly identical major-element composition and extent of crystallization would penetrate to the same crustal level in response to apparently identical conditions of stress and adopt the same paleomagnetic polarity over a span of four million years. Because the dikes show a much closer compositional relationship to lavas of the John Day Formation than to any known rocks of the Clarno Formation, and because the age (31.5 m.y.) of John Day mafic lavas only 3 mi northwest of the dikes (Evernden and others, 1964) matches the average age (31.4 m.y.) of dikes reported by Enlows and Parker, I conclude that 31.5 m.y. is the best currently available estimate of the age of the mafic dike system in the Mitchell area.

Clarno-John Day boundary problem

Enlows and Parker (1972) placed the dikes within the "indicated span of Clarno igneous activity in the Mitchell quadrangle" which lasted "from about 46 million years before pres-

Table 2. K-Ar ages from upper Clarno and lower John Day Formations in the vicinity of Mitchell, Painted Hills, and Clarno Bridge

Age (m.y.)	Material	Location	Stratigraphic position	Reference
29.3 ± 0.5 29.4 ± 0.6	Whole rock	1 mi SE of Mitchell	Nelson Creek dikes	Enlows and Parker, 1972
31.1	Sanidine	Painted Hills	Tuff bed 165 ft above base of John Day Formation	Evernden and others, 1964
31.5	Whole rock	Between Mitchell and Painted Hills	Basalt lava in lower red John Day Formation	Evernden and others, 1964
32.0	Sanidine	1 mi E of Clarno Bridge	Altered tuff at base of John Day Formation	Evernden and James, 1964
30.1 ± 4.7 35.6 ± 3.4	Whole rock	4.5 mi E of Mitchell	Andesite lava, "upper Clarno"	Enlows and Parker, 1972
33.3 ± 1.2 33.5 ± 1.3	Whole rock	1.5 mi NW of Mitchell	Airport dikes	Enlows and Parker, 1972
34.0	Plagioclase	2 mi NE of Clarno Bridge	"Nut Beds" at top of Clarno Formation	Evernden and James, 1964
36.4 ± 1.1	Sanidine	2.2 mi SW of Ashwood	"Member A" at base of John Day Formation	Swanson and Robinson, 1968
36.5 ± 0.9	Sanidine	1.5 mi SW of Painted Hills	Crystal tuff near top of Clarno Formation	Evernden and others, 1964
37.5	Whole rock	Between Mitchell and Painted Hills	Andesite lava near top of Clarno Formation	Evernden and others, 1964

ent to 30 million years before present" and "was immediately succeeded by the deposition of the extensive volcaniclastic sediments of the John Day Formation" (p. 105 and Table 1). This interpretation was supported by an average age of 32.8 m.y. for a Clarno lava sample (KFO-901) collected 4.5 mi east of Mitchell.* In opposition to this interpretation was the 36-m.y. age of a widespread welded ash-flow sheet in "member A" at the base of the John Day Formation (Swanson and Robinson, 1968). Table 2 lists published K-Ar ages of Clarno and John Day rocks pertinent to this boundary problem. Much discussion in recent years has centered upon the possibility of simultaneous Clarno and John Day volcanism in central Oregon.

Inconsistencies between published radiometric ages and known stratigraphic relationships can be removed by reconsideration of three K-Ar determinations. "Member A" (36.4 m.y.) at the base of the John Day Formation overlies bedded John Day tuff (32.0 m.y.) and bedded Clarno tuff (34.0 m.y.) at Clarno Bridge (Evernden and James, 1964; Evernden and others, 1964). These bedded tuffs have been altered to bentonitic clay, and, as suggested by Swanson and Robinson (1968), their feldspars could have lost argon, giving rise to younger ages. The basal ash-flow tuff of "member A," in contrast, is a relatively fresh unit, and its age is probably more reliably estimated. The age of the "upper Clarno" andesite lava (KFO-901) from Mitchell (av. 32.8 m.y.) is erroneous because, in my opinion, it belongs stratigraphically in the lower Clarno Formation. An unpublished K-Ar age of 48.9 ± 5.2 m.y. (Enlows, Robinson, and McKee, personal communication) has been obtained on hornblende separated from another andesite flow in a nearly equivalent stratigraphic position, 3.4 mi northeast of Mitchell. In addition, volcanic mudflow deposits at approximately the same stratigraphic level as the nearby 48.9-m.y. hornblende andesite lava have been intruded by the mafic rocks of Marshall Butte. The average of two Marshall Butte age measurements is 44.9 m.y. (Enlows and Parker, 1972). It is my conclusion that in the vicinity of Mitchell, Painted Hills, and Clarno Bridge, deposition of the Clarno Formation ceased and was rapidly followed by deposition of the John Day Formation approximately 36 million years ago.

Early Oligocene deformation

The lower ash-flow tuff of "member A" at the base of the John Day Formation appears to have spread across the trace of the Blue Mountain anticline eastward to within 13 mi of Mitchell (Robinson, 1975). Most of the later John Day ash-flow tuffs were prevented from spreading that far to the east by a topographic barrier coincident with the Blue Mountain anticline (Robinson, 1966). Uplift of the Blue Mountain anticline probably produced the topographic barrier after much of the lower John Day Formation had been deposited. These relationships are compatible with an episode of northwest-southeast compressional deformation of sufficient intensity to produce broad folds and strike-slip faults and to release relatively small volumes of deep-seated mafic magmas to the surface during early Oligocene time in north-central Oregon.

The obvious magmatic distinctions between Clarno and John Day volcanism developed independently from, and some five million years prior to, the onset of crustal deformation that produced folds in John Day rocks. It is suggested that lower John Day tuffs will be found resting conformably on upper Clarno rocks in some localities and that an angular unconformity will be recognized between lowermost John Day tuffs and overlying John Day tuffs where preservation and exposure permit careful measurement. In similar fashion, strike-slip movement on the Mitchell fault probably displaced lower John Day tuffs but not overlying members of the John Day Formation.

* It should be recorded that the location of KFO-901 is given incorrectly by Enlows and Parker; it was taken from the summit of hill 4703, in the SW ¼ of sec. 35, T. 11 S., R. 21 E. (K.F. Oles, personal communication).

ACKNOWLEDGEMENTS

My appreciation is extended to K.F. Oles and H.E. Enlows for their assistance in reading the manuscript of this paper.

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Oregon oil and gas activity for first half of year

The 1980 oil and gas exploration and drilling activity in Oregon was summarized earlier this year (*Oregon Geology*, March 1981). Since the first of the year, however, 13 permits to drill have been granted, with an additional four pending at this time. Seven wells have been drilled this year, for a total of 34,589 ft.

Demand for drilling rigs in other parts of the country has held Oregon's rig count to one or two during the spring months, but an additional rig is expected for the remainder of the year. Drilling so far in 1981 has been confined to the western part of the state, with the exception of one hole in Crook County in central Oregon. Operators have included American Quasar Petroleum Company; Diamond Shamrock Corporation; John Miller; and Texaco, Incorporated.

In March, American Quasar discovered Oregon's second gas field a mile west of Lebanon in the Willamette Valley. The well, Hickey 9-12, produces at a rate of 200,000 cubic feet per day from sands at a depth of 3,000 ft.

Oil and gas permits and drilling activity since January 1981

Permit number	Operator	Well name	Location	PTD: Proposed (ft) TD: Total depth (ft)	Status
176	American Quasar Petroleum Co.	Franbea 36-34	SE¼ sec. 36 T. 7 N., R. 5 W. Columbia Co.	PTD 5,000	Permitted 1/21/81
177	Diamond Shamrock Corporation	Boise Cascade 11-14	NW¼ sec. 14 T. 5 N., R. 7 W. Clatsop Co.	TD 7,864	Abandoned dry hole
178	Diamond Shamrock Corporation	Crown Zellerbach 11-28	NW¼ sec. 28 T. 5 N., R. 9 W. Clatsop Co.	TD 5,700	Abandoned dry hole
179	Diamond Shamrock Corporation	Crown Zellerbach 31-17	NE¼ sec. 17 T. 6 N., R. 8 W. Clatsop Co.	PTD 10,000	Drilling
180	Reichhold Energy Corporation	Columbia Co. 32-10	NE¼ sec. 10 T. 6 N., R. 5 W. Columbia Co.	PTD 8,000	Permitted 3/3/81
181	Reichhold Energy Corporation	Columbia Co. 23-5	SW¼ sec. 5 T. 6 N., R. 5 W. Columbia Co.	PTD 3,500	Permitted 3/12/81
182	Reichhold Energy Corporation	Columbia Co. 13-1	SW¼ sec. 1 T. 6 N., R. 5 W. Columbia Co.	PTD 3,500	Permitted 3/12/81
183	Reichhold Energy Corporation	Hemeon 14-14	SW¼ sec. 14 T. 6 N., R. 5 W. Columbia Co.	PTD 2,700	Permitted 3/12/81
184	Reichhold Energy Corporation	Longview Fibre 41-32	NE¼ sec. 32 T. 7 N., R. 5 W. Columbia Co.	PTD 3,200	Permitted 4/10/81
185	American Quasar Petroleum Co.	Kenneth Wetgen 26-32	NE¼ sec. 26 T. 13 S., R. 4 W. Linn Co.	PTD 5,000	Permitted 4/2/81
186	American Quasar Petroleum Co.	Wolverton 13-31	NE¼ sec. 13 T. 10 S., R. 3 W. Marion Co.	PTD 5,000	Permitted 4/21/81
187	Reichhold Energy Corporation	Ellis 23-26	SW¼ sec. 26 T. 5 N., R. 4 W. Linn Co.	PTD 4,000	Permitted 4/29/81
188	American Quasar Petroleum Co.	Chipman 4-14	SW¼ sec. 4 T. 12 S., R. 2 W. Linn Co.	PTD 5,000	Permitted 6/09/81
	Miller Drilling Co.	Bork 2	SE¼ sec. 26 T. 8 S., R. 5 W. Polk Co.	PTD 1,000	Application
	Reichhold Energy Corporation	Lee 32-32	NE¼ sec. 32 T. 7 N., R. 5 W. Columbia Co.	PTD 2,600	Application

(Continued on next page.)

Permit number	Operator	Well name	Location	PTD: Proposed (ft) TD: Total depth (ft)	Status
	Reichhold Energy Corporation	Paul 34-32	SE¼ sec. 32 T. 7 N., R. 5 W. Columbia Co.	PTD 3,150	Application
	American Quasar Petroleum Co.	Benson Timber 8-14	SW¼ sec. 8 T. 6 N., R. 4 W. Columbia Co.	PTD 5,000	Application

□

ABSTRACT

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

GEOLOGY AND GEOCHEMISTRY OF VOLCANIC ROCKS IN THE DETROIT AREA, WESTERN CASCADE RANGE, OREGON, by Craig McKibben White (Ph.D., University of Oregon, 1980)

Data on compositional variations of igneous rocks are needed before competing models for the generation of magma at convergent plate boundaries can be realistically evaluated. The Neogene volcanic rocks of the Detroit area were selected to provide this information because they contain a relatively complete record of volcanism through most of late Cenozoic time.

The area mapped for this study is located wholly within the Western Cascade physiographic province and includes adjoining parts of the Detroit, Battle Ax, Mount Jefferson, and Breitenbush Hot Springs 15-minute quadrangles. Detailed mapping was augmented by radiometric dating in order to provide essential stratigraphic and chronological control for compositional studies.

Volcanic rocks in the Detroit area have been assigned to the following stratigraphic units: High Cascade Series (Quaternary); Outerson Formation (Pliocene); Elk Lake Formation (upper Miocene); Sardine Formation (middle Miocene); and two interfingering units, the Breitenbush Formation and the Scorpion Mountain lavas (upper Oligocene and lower Miocene). The Scorpion Mountain lavas consist of distinctive, dark-colored, generally aphanitic flows and dikes that range in composition from basaltic andesite through dacite. Flows in this unit have been mistakenly identified as Columbia River basalt; however, mapping indicates they were erupted within the Western Cascade Range, and radiometric dating has clearly shown they predate Columbia River basalt by as much as 10 m.y.

Ninety specimens from the various units exposed in the Detroit area were analyzed for ten major elements and Rb, Sr, Zr, and Ni. In addition, the abundances of Ba, Hf, Th, Cr, Sc, and seven rare-earth elements were determined for 20 samples. Compositional data show that upper Oligocene-lower Miocene lavas in the Detroit area have low contents of Al_2O_3 and high ratios of Fe/Mg characteristic of lavas in the tholeiitic rock series. Younger lavas in the map area are overwhelmingly calc-alkaline in geochemical character. Rocks in the oldest age groups also differ from younger Cascade lavas by having higher values of TiO_2, K_2O, Rb, Zr, and Sc, and lower contents of CaO, Sr, Ni, and Cr.

The differences in major-element and included trace-element contents between the oldest lavas and those in younger suites can best be explained by a shift in the assemblage of early-stage liquidus minerals. The trends in the oldest lavas are consistent with fractionation of olivine + plagioclase + Cr-rich spinel ± clinopyroxene; those in the younger suites indicate fractionation of amphibole ± olivine ± clinopyroxene. The progressive decrease in contents of K_2O and excluded trace elements in the Detroit area lavas is compatible with a process of zone refining and depletion of mantle or lower crustal rocks in these elements with time.

Trends in the compositions of Quaternary lavas erupted from volcanic centers at Battle Ax Mountain and Mount Jefferson have been used to evaluate petrologic processes on the scale of a single volcano. Lavas in these suites show a progressive increase in SiO_2 contents with time, but data on trace-element abundances indicate each volcano produced at least three compositionally distinctive groups of flows. The initial contents of Rb, Zr, Hf, and La in each sequence of lavas are lower than those of the previously erupted group. The "resetting" of trace-element concentrations without a corresponding return to low values of SiO_2 suggests that magma reservoirs were replenished with magma that was strongly depleted in incompatible trace elements but produced lavas that were differentiated to a pre-established level. Repeated partial melting of a large volume source in the mantle could produce consecutive batches of magma with progressively lower contents of dispersed elements. □

Engineering Geologist meeting set for Portland

The National Association of Engineering Geologists will hold its twenty-fourth annual meeting this September in Portland. The meeting consists of three days of technical sessions starting on September 28, 1981. Field trips will be conducted before and after the technical sessions. Because of Portland's proximity to Mount St. Helens, special sessions and field trips are planned to focus on the engineering problems associated with the aftermath of a volcanic eruption.

Technical session topics include nuclear waste disposal; non-nuclear waste disposal; open sea engineering geology; high energy or emerging coastlines; recovery from earthquakes, volcanic events, and other geologic disasters; instrumentation; ground water; and hydrogeology. Risk analysis and liability are the topics of the symposia. Five field trips scheduled include (1) Hanford Nuclear Reservation-Columbia River, (2) Cascade Range-Central Oregon, (3) Oregon Coast, (4) Mount St. Helens-Toutle River, and (5) Mount St. Helens-Lewis River.

Details about all events appear in the January, April, and July issues of the A.E.G. Newsletter. For information or registration forms contact Ken Robbins, Dames and Moore, 1220 SW Morrison, Portland, Oregon 97205; phone (503) 228-7688.

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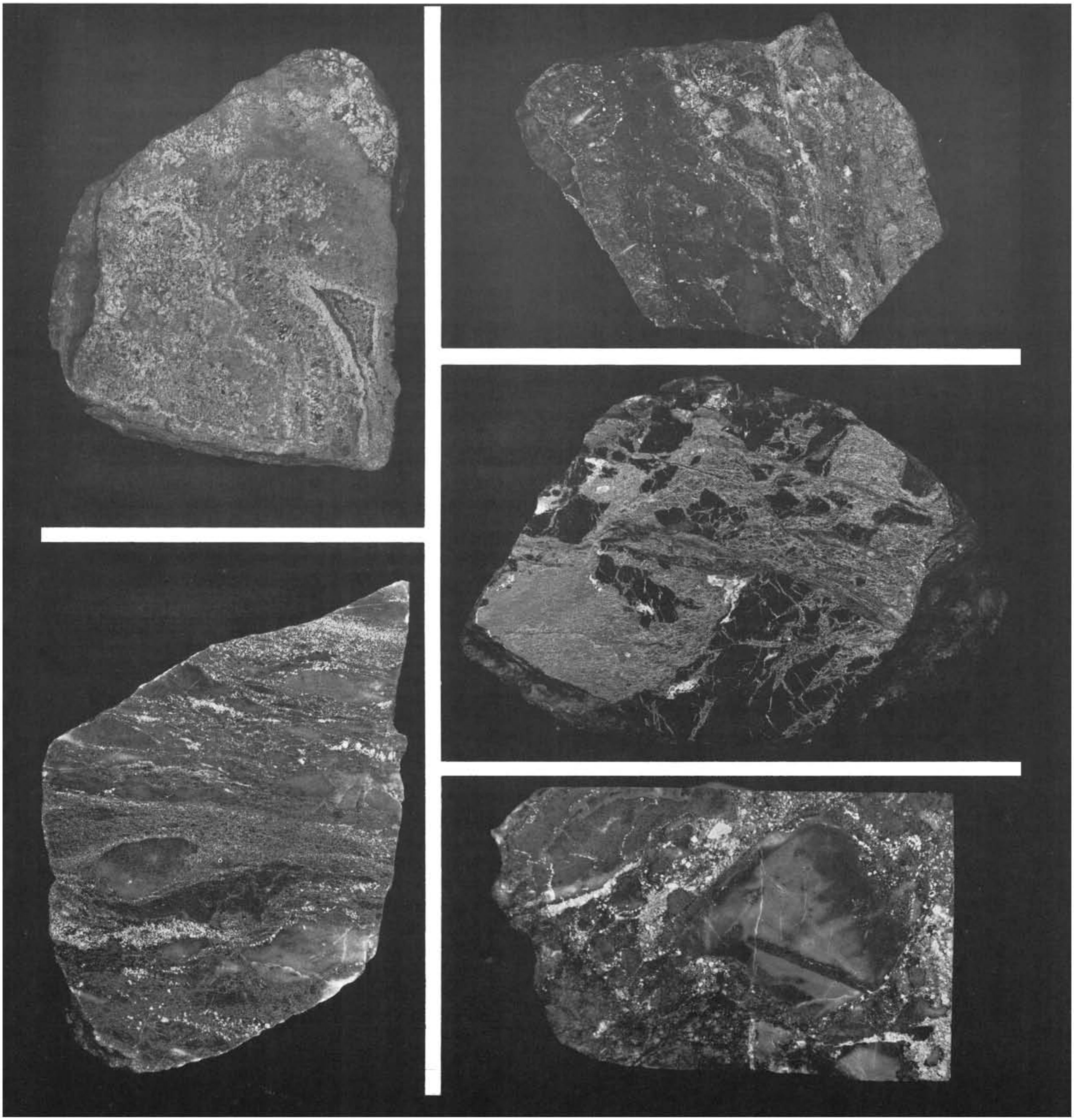

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COVER PHOTO

Polished slabs from massive sulfide deposits in southwestern Oregon. Clockwise, from upper left: massive pyrite (light and medium gray) and sphalerite (dark gray) with colloform banding, Queen of Bronze Mine; coarse breccia composed of pyrite and chalcopyrite (concentrated in right half) and mafic rock fragments, Queen of Bronze Mine; sheared chalcopyrite-pyrrhotite lenses (light) and chloritic matrix (dark), Waldo Mine; mixed chert-volcanic-sulfide (pyrite and chalcopyrite) breccia, Turner-Albright Mine; layered sulfide (pyrite, chalcopyrite, and sphalerite) and barite with numerous barite lenses, Silver Peak Mine. All samples are approximately 10 cm across. Photographed by Lowell Kohnitz, U.S. Geological Survey. See article beginning next page.

DOGAMI releases new bibliography, map index, lineation study, and geologic maps

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the release of the following new publications:

Bulletin 102—*Bibliography of the Geology and Mineral Resources of Oregon (Seventh Supplement, January 1, 1976, to December 31, 1979)*, compiled by Debbie Burnetti, Editor, GeoRef, and Klaus Neuendorf, Editor/Librarian, Oregon Department of Geology and Mineral Industries. Produced in cooperation with GeoRef, the computerized information system of the American Geological Institute, this 68-page book presents bibliographic information from 1976 through 1979 on the geology and mineral resources of Oregon. Entries are indexed by author's name, subject, county, and rock unit. Bulletin 102, the seventh supplement to the Department's original bibliography compiled in 1936 by R.C. Treasher and E.T. Hodge, sells for $4.00.

Special Paper 13—*Faults and Lineaments of the Southern Cascades, Oregon*, by C.F. Kienle, C.A. Nelson, and R.D. Lawrence, Foundation Sciences, Inc. This lineament and fault analysis of topographic maps and SLAR, Landsat, and U-2 high-flight imagery was completed as the initial stage of the geothermal assessment of the southern Cascades funded by a grant from the U.S. Department of Energy to the Oregon Department of Geology and Mineral Industries. The 23-page text describes procedures used to interpret data, criteria used to define lineaments, and geologic control of the expression of faults and lineaments and presents a tectonic interpretation of the study area. Included with the text are two two-color topographic maps (scale 1:250,000) on which thermal and nonthermal springs, lineaments, and known faults are plotted. Cost of Special Paper 13 is $4.00.

Geological Map Series GMS-14—*Index to Published Geologic Mapping in Oregon, 1898-1979*, by C.A. Schumacher, Cartographer, Oregon Department of Geology and Mineral Industries. GMS-14 shows areas in Oregon that have been covered by geological, geophysical, ground-water, mineral-locality, and other types of maps that have appeared in publications by DOGAMI, U.S. Geological Survey, Bureau of Mines, and others. The index, which replaces DOGAMI's Miscellaneous Paper 12 (*Index to Published Geologic Mapping in Oregon, 1898-1967*), consists of six two-color maps (scale 1:1,000,000) on a U.S. Geological Survey quadrangle-index base, with county names and boundaries for easy reference. Each map has an extensive bibliography and is designed so that the reader may easily determine available maps, along with authors, titles, and dates, for any given area in Oregon. GMS-14, the only available comprehensive index to

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Massive sulfide deposits in oceanic-crust and island-arc terranes of southwestern Oregon

by Randolph A. Koski, U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025, and Robert E. Derkey, Department of Geology, University of Idaho, Moscow, Idaho 83843

INTRODUCTION

Massive sulfide deposits containing significant amounts of base and precious metals occur in oceanic-crust and island-arc terranes of the northern Klamath Mountains in southwestern Oregon. These terranes constitute parts of two major lithotectonic belts separated by an east-dipping thrust fault: the upper-plate western Paleozoic and Triassic belt and the lower-plate western Jurassic belt. Irwin (1960, 1966) first proposed and elaborated the concept of internally complex north-south-trending arcuate lithic belts of regional extent juxtaposed in the Klamath Mountains. Subsequently, the geologic and tectonic settings of coherent terranes within these belts have been identified (for example, Irwin, 1972, 1977; Garcia, 1979; Johnson, 1980); and plate-tectonic models for Klamath evolution through plate convergence, eastward-directed subduction, and accretion of oceanic rocks to the western continental margin of North America have been evolved (Hamilton, 1969, 1978; Davis and others, 1978).

In this report we discuss the massive sulfide deposits of southwestern Oregon within this recently established plate-tectonic framework. These deposits (Figure 1) include the Queen of Bronze, the Cowboy, and others occurring in tectonic mélange of the western Paleozoic and Triassic belt; the Turner-Albright in ophiolite of the western Jurassic belt; and the Silver Peak and Almeda in fragmental island-arc volcanic rocks of the western Jurassic belt. Together, these deposits have produced nearly one-third (approximately 4,000 tons) of Oregon's total copper output, more than 70,000 troy ounces of silver and 2,000 troy ounces of gold, and minor amounts of lead and zinc. Although none of these deposits is currently being mined, all have been the focus of company activity during the last decade, and exploration activity continues at present.

DEPOSITS IN OCEANIC-CRUST TERRANES

Ophiolites are pseudostratigraphic assemblages of ultramafic and mafic rocks that appear to represent displaced and uplifted fragments of ancient oceanic crust and the upper mantle. Where complete, an ophiolite assemblage includes tectonized harzburgite and dunite, layered gabbro, sheeted diabase dike complexes, and pillow basalt. The basalt is commonly overlain by fine-grained marine sedimentary rocks, such as chert, shale, and limestone. Pillow lavas of ophiolite complexes in Cyprus, Turkey, Newfoundland, Italy, and many other localities are important hosts for "Cyprus-type" massive Fe-Cu sulfide deposits.

The occurrence of ophiolite assemblages within the major tectonic belts of the northern Klamath Mountains was summarized by Irwin (1977). Two of the largest and best known exposures of ophiolite—the Preston Peak ophiolite in the western Paleozoic and Triassic belt and the Josephine ophiolite in the western Jurassic belt—are associated with massive-sulfide mineralization.

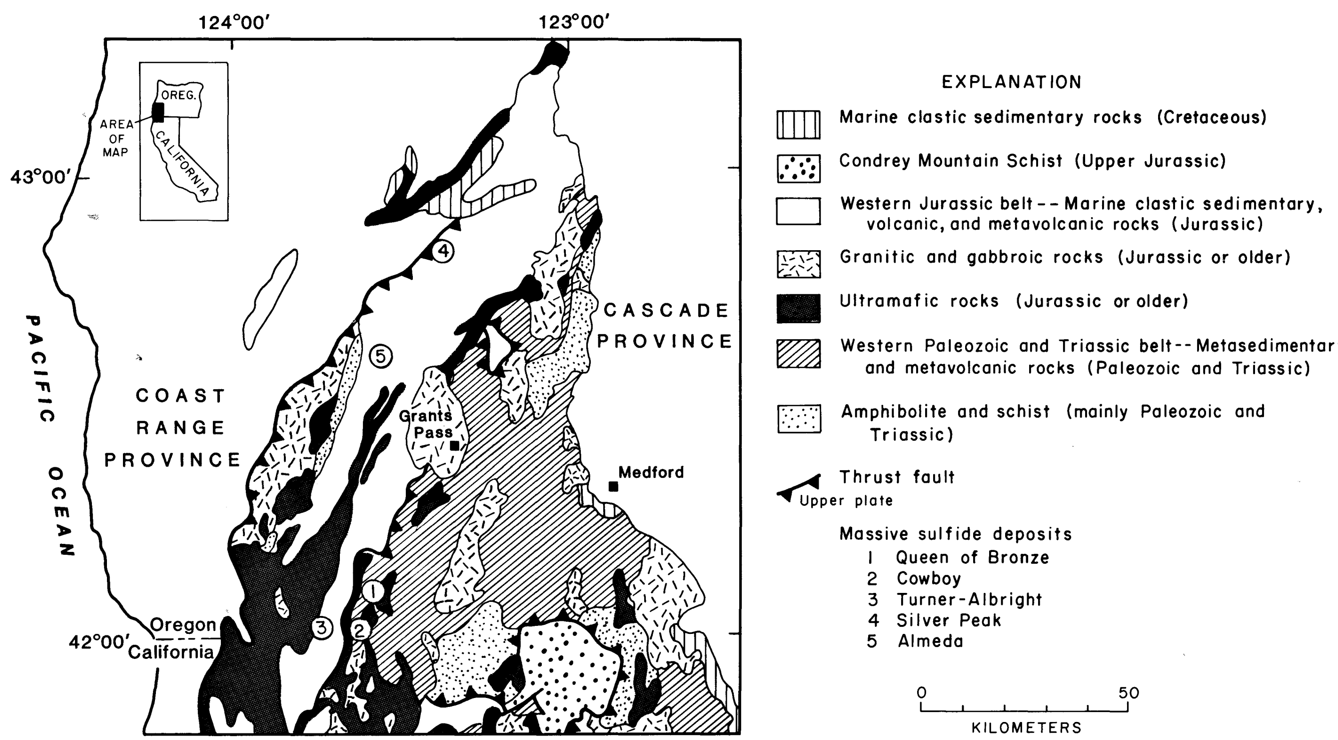

Figure 1. Generalized geologic map of northern Klamath Mountains, showing location of major massive sulfide deposits. (Geology modified from Hotz, 1971)

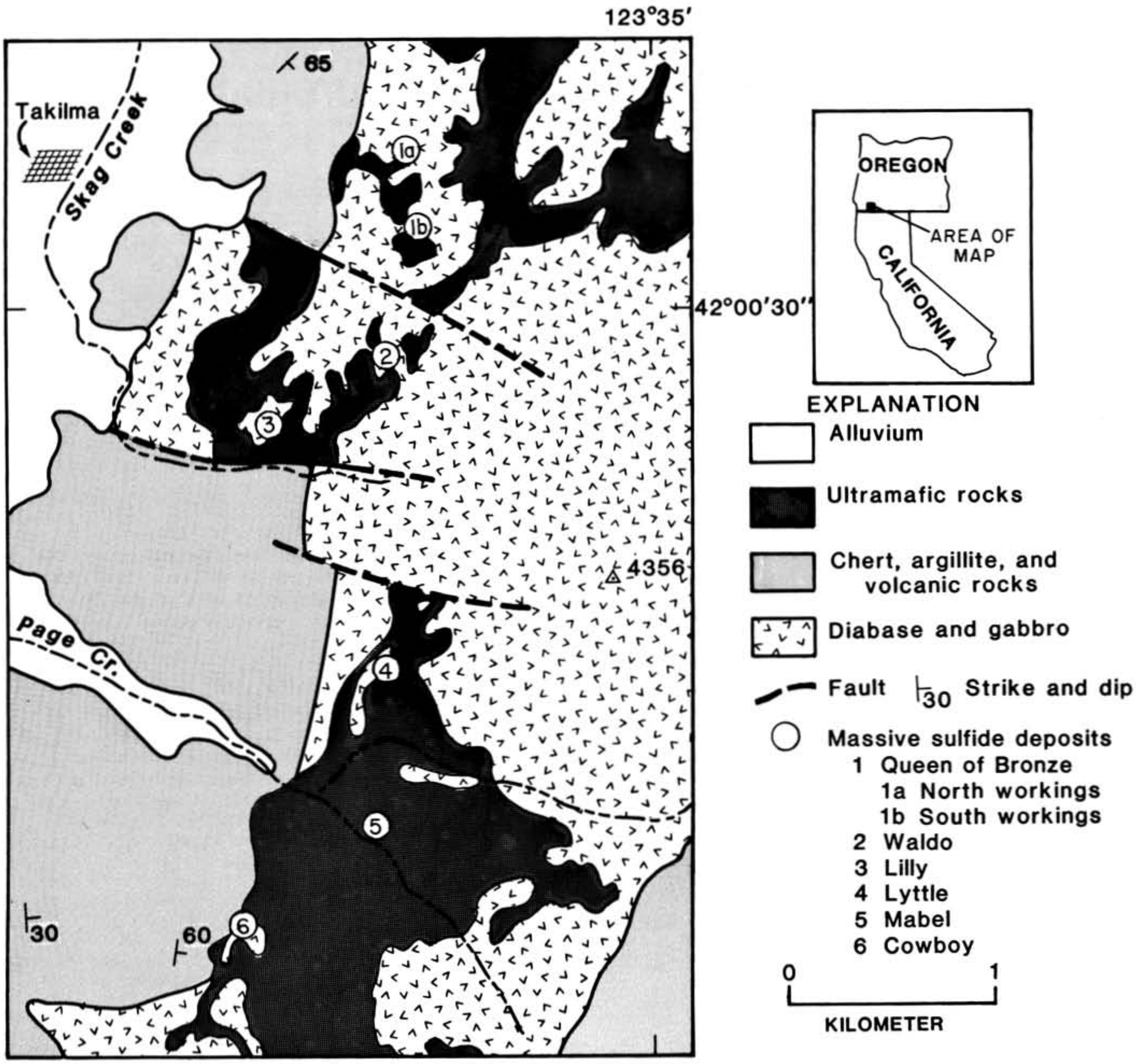

Figure 2. Geologic map of the Takilma area, Oregon, showing location of massive sulfide deposits.

Takilma-area deposits

Near Takilma, Oregon, at the west edge of the western Paleozoic and Triassic belt, small masses of pyritic and pyrrhotitic massive sulfide are dispersed within tectonic mélange composed of mafic and ultramafic rocks (Figure 2). The mafic rocks include diabase and diabase breccia, gabbro, diorite, and minor basalt showing varying degrees of greenschist-facies metamorphism. Exposures at the Queen of Bronze Mine and along the east fork of the Illinois River show that the diabasic and gabbroic rocks form dike or sill aggregates, although a well-developed sheeted-dike complex has not been identified. The mafic assemblage is in apparent fault contact with, and is overlain by, a sequence of thin-bedded gray radiolarian chert, argillite, graywacke, pebble conglomerate, rare limestone, and intercalated vesicular mafic lava flows.

The mafic rocks and overlying strata are intruded and engulfed by large irregular masses of strongly serpentinized peridotite. Subrounded blocks of metadiabase, metagabbro, chert-argillite, and massive sulfide ranging in size from smaller than a meter to hundreds of meters across are incorporated into the ultramafic bodies. Contacts between the larger inclusions and serpentinite are typically sheared. The rock assemblage in the Takilma area is lithologically similar to that in the Preston Peak ophiolite 15 km to the south (Snoke, 1977). Field and geochemical evidence indicate to Snoke (1977) and Snoke and others (1977) that the ophiolitic ultramafic, mafic, and sedimentary rocks at Preston Peak represent the vestiges of an immature island-arc complex floored by oceanic lithosphere.

More than 40,000 tons of ore averaging greater than 5 weight percent Cu have been mined from at least six localities in the Takilma district (Shenon, 1933a). The sulfide mineralization is discontinuous and occurs within a 4-km-long north-south-trending zone that follows the irregular contact between mafic and ultramafic rocks (Figure 2). Deposits in the diabasic wall rocks (Queen of Bronze, Waldo, Lilly, and Lyttle) consist of sharply defined pods, wedges, tabular lenses, and thin discontinuous seams of sulfide and quartz; these bodies generally have sharp contacts with unmineralized diabase. Sulfide textures range from fine-grained massive-granular to coarse-brecciated; a few crudely layered and colloform features are also preserved. The mafic wall rocks show pervasive but varying degrees of recrystallization and alteration to the spilitic assemblage chlorite-actinolite-epidote-albite-calcite. Furthermore, the mafic rocks in contact with serpentinite are locally altered to pale-green rodingite composed of hydrogarnet, idocrase, chlorite, diopside, and prehnite.

Mineralization in the ultramafic rocks (Cowboy and Mabel) consists of aggregates of closely spaced rounded massive sulfide "boulders" (Shenon, 1933a) in highly sheared serpentinite. Sulfide textures typically are coarse grained massive-granular, banded, or foliated. These textures appear to reflect metamorphic recrystallization and deformation by flowage. In addition to serpentine-group minerals (mostly antigorite), the ultramafic wall rock locally contains talc and magnesite.

Principal sulfide minerals at the Queen of Bronze deposit (both the north and south workings) are, in decreasing abundance, pyrite, chalcopyrite, sphalerite, and pyrrhotite. At the Waldo deposit, pyrite, pyrrhotite, and chalcopyrite are all abundant; sphalerite and arsenopyrite are minor constituents. Pyrrhotite and chalcopyrite are the major phases in massive sulfide from the Lyttle, Mabel, and Cowboy deposits. Sphalerite and cubanite are abundant phases in some samples, and pyrite is very minor. Shenon (1933a) also reports the presence of cobaltite in "boulder" ore from the Cowboy Mine. The sulfide minerals are accompanied by varying amounts of interstitial quartz and less abundant chlorite, calcite, and serpentine minerals. Serpentinite at the Cowboy deposit hosts minute stringers and blebs of pyrrhotite and chalcopyrite.

The deposits in the Takilma area appear to represent a discontinuous zone of sulfide mineralization within a complex of diabase and gabbro dikes and diabasic breccia, analogous to the mafic complex in the Preston Peak ophiolite described by Snoke (1977). Locally, the form and texture of primary sulfide mineralization indicate that open-space precipitation was an important process. Subsequent faulting and the movement and serpentinization of peridotite have resulted in disruption, brecciation, recrystallization, and deformation of the sulfide bodies in the serpentinite.

Turner-Albright deposit

Thirteen km southwest of Takilma, the Turner-Albright copper-gold deposit occurs in basaltic lavas and lava breccia of the Josephine ophiolite associated with the western Jurassic belt (Figure 1). Cunningham (1979) reports that the average grade of the deposit is 2.5 weight percent Cu, 0.5 weight percent Zn, and 0.025 troy ounces Au per ton. No production of base metals has been reported from the Turner-Albright Mine, although the gossans have been treated for small amounts of gold. Recent regional geologic studies by Vail (1977) and Harper (1980) have led to a recognition of a complete ophiolite section that includes the Josephine Peridotite, a harzburgite tectonite, at its base. The peridotite is tectonically overlain by ultramafic and gabbroic cumulate, massive gabbro, sheeted diabase dikes, mixed pillow lava and pillow-lava breccia, and a thin layer of metalliferous chert and mudstone. Thick flysch deposits containing interbedded graywacke, slate, and conglomerate conformably overlie the ophiolite section (Harper, 1980). Figure 3 is a geologic section through the Josephine ophiolite. Field relations and petrographic and geochemical data indicate that the Josephine ophiolite formed in a marginal basin between the North American Plate margin and an offshore volcanic arc during Jurassic time (Dick, 1977; Vail, 1977; Harper, 1980).

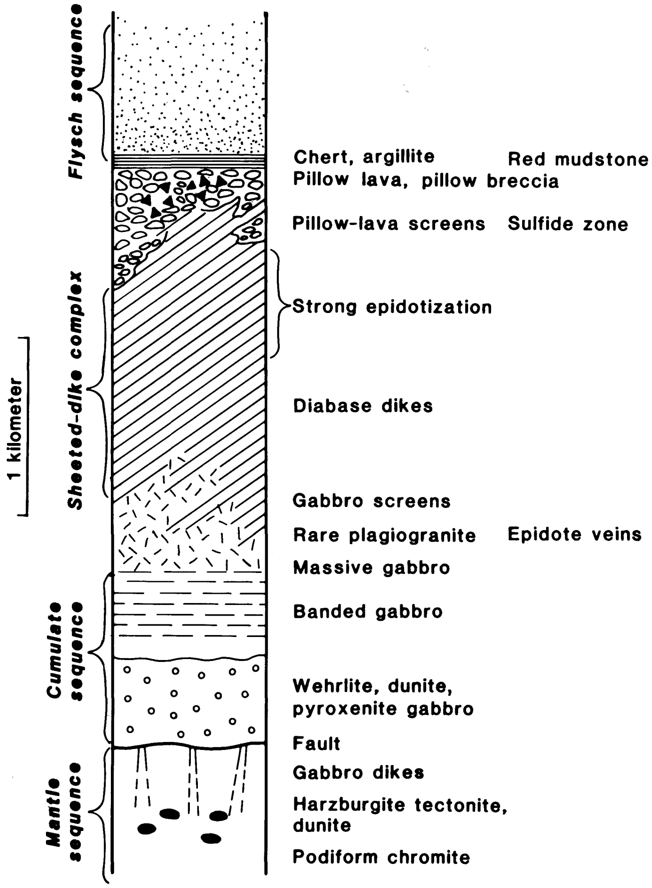

Figure 3. Geologic section of the Josephine ophiolite. (Modified from Harper, 1980)

Cunningham (1979) recently described the geology and geochemistry of the Turner-Albright deposit and the associated ophiolitic rocks. The mineralization occurs within the upper plate of an east-dipping thrust fault; the footwall of the thrust is barren peridotite (Figure 4a). The rocks hosting massive, vein, and disseminated sulfide consist of spilitized mafic lavas and volcanic breccia intruded by comagmatic diabase and gabbro. Pyritic lenses of bedded fossiliferous tuff and tuffaceous shale intercalated within the volcanic pile are supportive evidence for a submarine eruptive episode.

As shown by cross section A-A′ (Figure 4b), the steeply northeast-dipping layer of massive sulfide breccia, expressed by prominent linear gossan zones at the surface, grades northward into a columnar zone of mixed volcanic rocks, chert, and sulfide breccia. The sulfide assemblage is dominated by pyrite, although chalcopyrite and sphalerite are common and locally abundant. In the zone of massive sulfide breccia, subangular to subrounded pyritic sulfide fragments occur in a matrix of finer grained pyrite, quartz, altered lithic fragments, chalcopyrite, and sphalerite. Many individual sulfide fragments display thin alternating bands of pyrite and sphalerite. Pyrite-, chalcopyrite-, and sphalerite-bearing veinlets that crosscut massive pyrite and banded pyrite-sphalerite fragments provide evidence for multiple episodes of sulfide deposition.

The mixed-breccia zone has the characteristics of a hydrothermal feeder system. The zone contains discontinuous sulfide veinlets and disseminations; many lithic fragments are

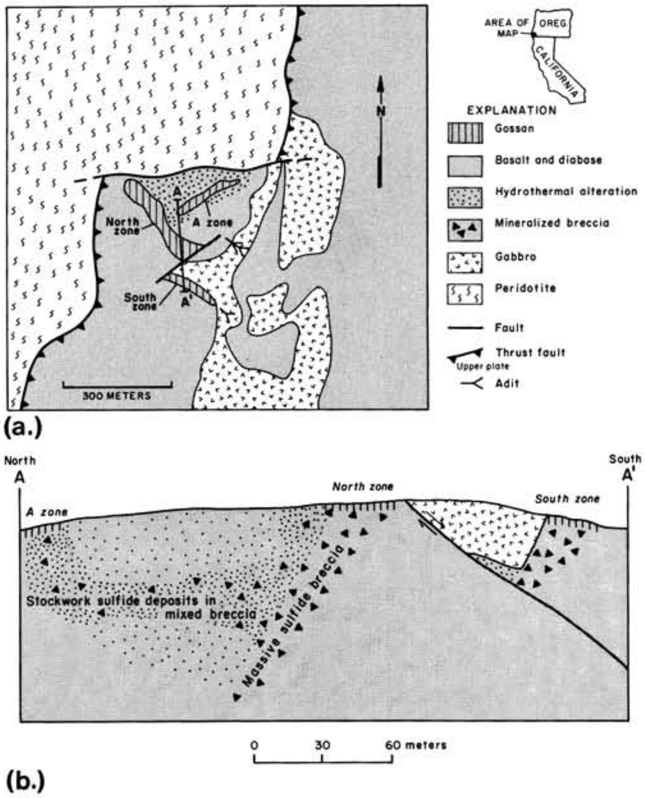

Figure 4. Geologic map (a) and cross section A-A' (b) of the Turner-Albright Mine. (Modified from Cunningham, 1979)

replaced by sulfides along their margins. Microcrystalline hematitic jasper forms veinlets and fills interstices between altered volcanic fragments. Adjacent volcanic wall rocks are strongly chloritized and silicified. The configuration of the feeder zone and tabular massive sulfide body suggests that the Turner-Albright deposit may be overturned to the southwest.

DEPOSITS IN ISLAND-ARC TERRANES

Felsic submarine lavas and pyroclastic rocks in calc-alkaline island-arc sequences host the important class of Kuroko-type massive sulfide deposits. These volcanogenic polymetallic deposits generally consist of one or more stratiform massive sulfide layers and lenses intercalated with volcanic strata and an underlying discordant stockwork mineralization of lower grade. The latter feature may represent the hydrothermal feeder system for the layered sulfide accumulations. Kuroko-type deposits in the Miocene Green Tuff province in Japan and in other island-arc complexes are important sources of base and precious metals.

Stratiform volcanogenic massive sulfide deposits occur in fragmental metavolcanic rocks of the Rogue and Galice Formations in the western Jurassic belt of southwestern Oregon. The texture, composition, and major- and trace-element patterns of the metavolcanic and volcaniclastic metasedimentary rocks indicate that the Rogue and Galice Formations represent a Jurassic island-arc sequence (Garcia, 1979). Much of the sulfide occurs within felsic pyroclastic units along two northeast-trending zones: (1) a northern zone southwest of Canyonville, and (2) a southern zone that crosses the Rogue River near Galice. The Silver Peak and Almeda are the most important deposits in the northern and southern zones, respectively (Figures 1 and 5).

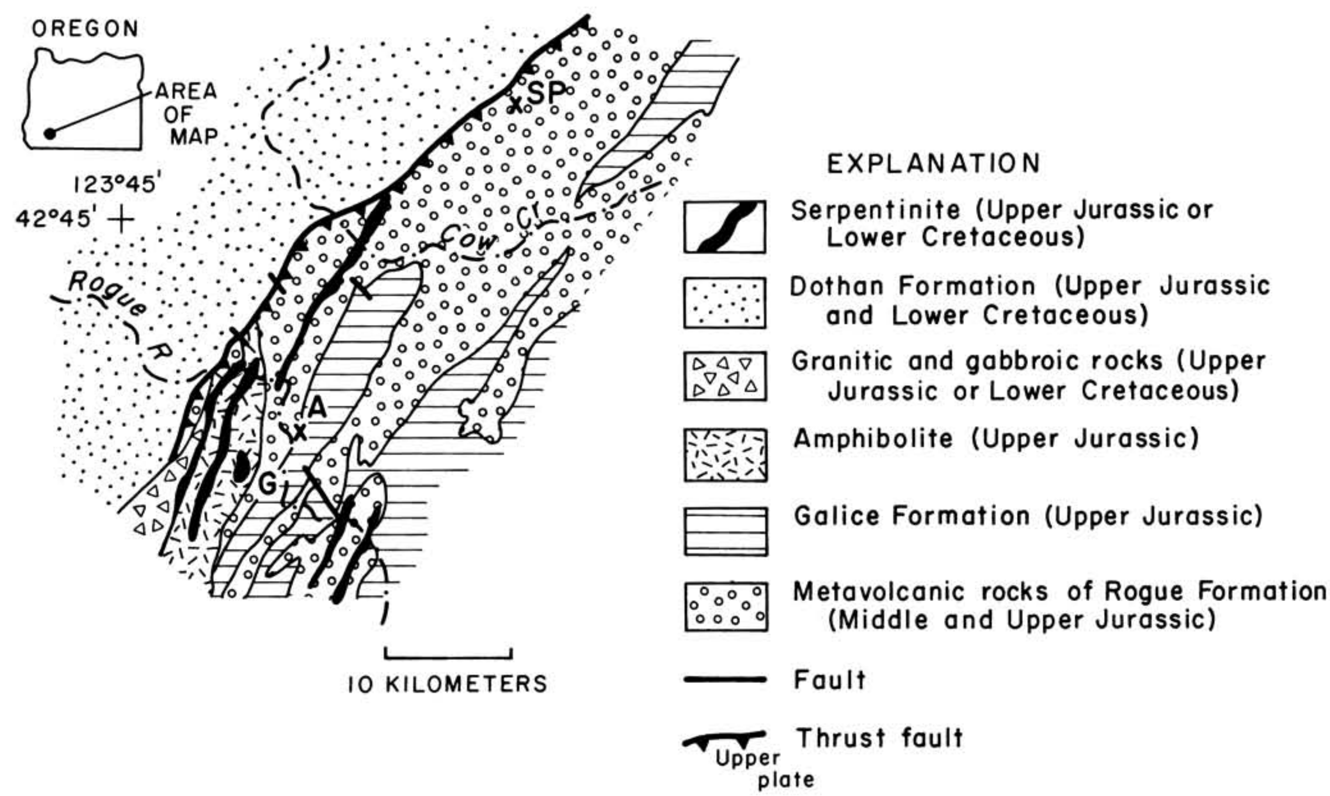

Figure 5. Regional geology surrounding the Silver Peak and Almeda Mine areas. G = Galice, SP = Silver Peak Mine, A = Almeda Mine. (Modified from Wells and Walker, 1953)

Silver Peak deposit

During the years 1926, 1928-31, and 1936-37, the Silver Peak Mine had a recorded production of 6,620 tons of ore from which 735,600 pounds of Cu, 21,980 troy ounces Ag, and 490 troy ounces Au were recovered (Ramp, 1972). During the period 1976-79, more than 12,000 ft of diamond drilling at the Silver Peak Mine and along the South Fork of Middle Creek 3 km southwest of Silver Butte penetrated several massive pyritic lenses, but copper-zinc mineralization comparable to that exposed in the Silver Peak Mine was not detected.

Jurassic metavolcanic rocks hosting the Silver Peak deposit lie in the upper plate of the Coast Ranges thrust and structurally overlie sedimentary rocks of the Dothan Formation (Figure 5). Johnson and Page (1979) have subdivided the greenschist-facies volcanic rocks near Silver Peak (previously the Rogue Formation) into a predominantly southeast-dipping sequence of rhyodacitic to andesitic flows, tuff, tuff breccia, agglomerate, and pillow basalt. Lava and tuff higher in the section (to the east) are interbedded with thin-bedded gray shale. The sequence is disrupted by southeast-dipping thrust faults and narrow slivers of serpentinite.

Figure 6 is a generalized geologic cross section of the Silver Peak deposit. The stratigraphically lowest unit exposed in the mine area, a vesicular andesite flow, is overlain by dacitic to rhyodacitic tuff and flows that grade upward into foliated tuff and tuff-breccia deposits. The uppermost unit in the sequence, exposed on nearby Silver Butte, consists of thin-bedded to massive siliceous tuff and interbedded tuffaceous sandstone.

All known mineralization in the Silver Peak area occurs within the foliated-tuff horizon (Figure 6), which is locally altered to aggregates of chlorite-talc-sericite or quartz-sericite. Flattened lapilli and pumice fragments also are present in the tuff. Graded tuff beds, fragments with altered margins, and load and flame structures within the mineralized zone all indicate subaqueous deposition.

Lenticular bodies of massive sulfide and barite as thick as 4 m parallel the plane of foliation over an exposed strike length of 90 m; layering within the massive sulfide also parallels the foliation. Lenses of foliated tuff as thick as 1 m occur in the massive sulfide. Additional sedimentary structures in the massive sulfide include load structures on the underlying tuff, graded bedding, and flame structures into the overlying tuff. Numerous disturbed structures disrupt bedding continuity.

Pyrite, the predominant sulfide mineral in the massive sulfide, generally occurs as subrounded grains in a matrix of one or more of the following minerals: quartz, barite, chalcopyrite, sphalerite, bornite, and Zn-rich tennantite. The individual pyrite grains appear to be detrital fragments cemented by other sulfide and gangue minerals. Small blebs of chalcopyrite, bornite, tennantite, and sphalerite are present in the pyrite, particularly pyrite grains surrounded by copper and zinc minerals. Galena is a very minor constituent of the ores at Silver Peak, and no silver minerals have been found.

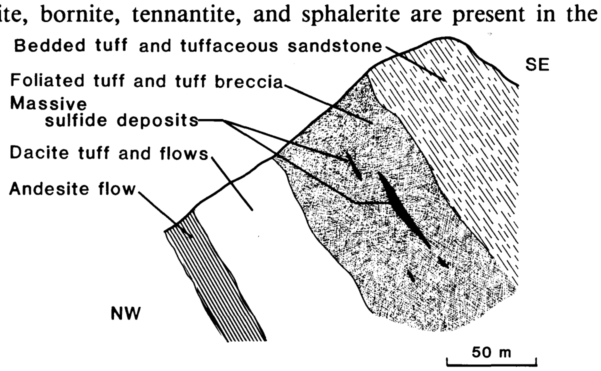

Figure 6. Generalized geologic cross section through the Silver Peak deposit.

Vertical zonation similar to that found in Kuroko-type deposits is evident in several underground exposures in which loosely bound massive pyrite (friable yellow ore) yields upward to dense massive pyrite-chalcopyrite (yellow ore), massive pyrite-sphalerite, tennantite-bornite-barite (black ore), and massive barite. Barite lenses are present in the black ore zone. Although massive ferruginous chert typical of Kuroko-type deposits is absent at Silver Peak, hematitic chert fragments as large as 3 cm in diameter are present in flow-banded tuff overlying the massive sulfide and massive barite. This flow-banded tuff unit also contains as much as 10 percent disseminated lapilli-size pyrite and chalcopyrite grains. The massive ore is locally underlain by 1-2 m of silicified tuff containing veinlets of pyrite, as well as disseminated pyrite, chalcopyrite, and bornite. However, no deep feeder system underlying the massive sulfide has been identified.

Almeda deposit

The Almeda Mine is situated on the north bank of the Rogue River, approximately 30 km southwest of the Silver Peak Mine. Shenon (1933b) reports that, between 1911 and 1916, 16,619 tons of ore produced from the Almeda deposit yielded 259,800 pounds of Cu, 7,197 pounds Pb, 1,540 troy ounces Au, and 48,387 troy ounces Ag.

Sulfide mineralization occurs in highly altered fragmental rhyolitic to dacitic metavolcanic rocks assigned to the Rogue Formation, immediately below the depositional contact with overlying slate and graywacke of the Galice Formation. Sill-like masses of dacite porphyry are emplaced along the Rogue-Galice boundary. The volcanic and sedimentary sequence occurs east of, and is in fault contact with, an ophiolite assemblage of amphibolite, metagabbro, and ultramafic rocks. Garcia (1979) suggests that this mafic-ultramafic complex represents the oceanic crust upon which the island arc that parented the Rogue and Galice Formations was constructed.

At the Almeda Mine, a 60-m-thick steeply east-dipping mass of intensely silicified fragmental rock known as the "Big Yank lode" occurs between clastic sedimentary rocks of the Galice Formation and coarse rhyolitic agglomerate. The mass contains lenses and fragments of massive sulfide and barite in a silicified volcanic matrix. Lenses of massive sulfide have a fragmental texture and contain clasts of sulfide, barite, and altered volcanic rock. Locally, alternating layers of sulfide and barite appear to be bedded deposits. The most abundant hypogene sulfide is pyrite, although chalcopyrite, sphalerite, and galena are locally concentrated in massive accumulations. Diller (1914, p. 75) refers to the stratiform mineralization here as "copper ore with barite."

Disseminated and vein sulfide, mostly pyrite, is present in silicified rock between the sulfide and barite lenses and lithic fragments and also forms an extensive stockwork in silicified volcanic breccia stratigraphically below the Big Yank lode. This low-grade stockwork zone reportedly contains anomalous gold and silver values (Shenon, 1933b) and is referred to as "siliceous gold-silver ore" by Diller (1914, p. 75). Quartz-sericite alteration and pyritization decrease in intensity below the Almeda deposit but extend southward from the Rogue River along the contact between the Rogue and Galice Formations. Sill-like masses of dacite porphyry emplaced near the contact are locally altered to fine-grained quartz and sericite accompanied by disseminated pyrite. With depth below the stratiform sulfide, quartz-sericite alteration diminishes, and the felsic volcanic rocks contain chlorite and epidote.

Table 1. Characteristics of principal massive sulfide deposits in southwestern Oregon

Deposit	Host rocks	Metals	Mineralization	Stockwork	Classification
Takilma area					
Queen of Bronze	Diabase, gabbro	Cu (Zn, Co, Au)	Pyrite, chalcopyrite, sphalerite, quartz, chlorite	No	Cyprus type(?)
Cowboy	Serpentinite	Cu (Co, Ni, Au, Zn)	Pyrrhotite, chalcopyrite, sphalerite, cubanite, cobaltite(?), quartz, antigorite, chlorite	No	Cyprus type(?)
Turner-Albright	Basalt, volcanic breccia	Cu (Au, Zn, Co)	Pyrite, chalcopyrite, sphalerite, quartz	Yes	Cyprus type
Almeda	Rhyolite to dacite breccia	Cu (Au, Ag, Zn, Pb)	Pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, barite, quartz	Yes	Kuroko type
Silver Peak	Dacite to rhyodacite tuff	Cu (Au, Zn)	Pyrite, chalcopyrite, sphalerite, tennantite, bornite, barite, quartz	?	Kuroko type

CONCLUSIONS

Table 1 lists major characteristics of the Queen of Bronze, Cowboy, Turner-Albright, Silver Peak, and Almeda sulfide deposits. These deposits in southwestern Oregon are believed to have been formed by submarine volcanogenic processes operating in distinct tectonic environments. The copper deposits near Takilma, Oregon, are components of a tectonic mélange and lack clearly defined stockwork zones; their spatial relation to volcanic centers is uncertain. However, the Fe-rich Fe-Cu-Zn sulfide assemblage, preservation of layered or fragmental massive-sulfide textures, and an ophiolitic wall rock environment all suggest an analogy with Cyprus-type cupreous-pyrite deposits. The sulfide-bearing ophiolitic rocks may have formed within a near-arc basin or at a subvolcanic level within a primitive island-arc environment. The zone of sulfide mineralization has been disrupted by later faulting and diapiric emplacement of serpentinite.

The geologic setting, stratigraphy, and composition of the Turner-Albright deposit strongly resemble those of Cyprus-type deposits. The stratiform zone of pyritic massive sulfide breccia and the associated stockwork veining and quartz-chlorite alteration occur in mafic volcanic rocks that stratigraphically overlie an extensive sheeted-dike complex in the Josephine ophiolite. Volcanism and sulfide deposition were contemporaneous at a site of sea-floor spreading in a Mesozoic marginal-basin environment.

The polymetallic Silver Peak and Almeda deposits, which have numerous Kuroko-type characteristics, occur in fragmental calc-alkaline volcanic rocks at separate stratigraphic intervals within the island-arc assemblage that include the Rogue and Galice Formations. Extensive quartz-sericite-pyrite mineralization in subjacent pyroclastic rocks at the Almeda Mine may represent a hydrothermal feeder system in the Rogue section. Massive sulfide and barite deposition are proximal with respect to the central vent. At Silver Peak, a thin but laterally extensive horizon of sulfide-bearing sericitic tuff underlies zoned massive sulfide and barite, but no deep stockwork zone has been located. Disrupted sulfide layers, fragments of massive barite in black ore, detrital sulfide, load structures, and graded bedding all indicate that the sulfides may have been transported downslope from a central vent by slumping and debris flow.

Albers (1981) discusses the syngenetic relation between certain mineral-deposit types and accreted "tectono-stratigraphic" belts. Deposits like those described in this report may occur elsewhere in the northern Klamath Mountains and offer a potential source for copper, gold, silver, zinc, cobalt, nickel, and barite. The recognition and interpretation of oceanic-crust and island-arc terranes in the Klamath province are key factors in exploring for base- and precious-metal deposits in southwestern Oregon.

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Oil and gas developments

State and county lease sales held during summer

An Oregon State Lands Division lease sale held July 8 and 9, 1981, offered over 107,000 acres in several counties and brought bonus bids totaling $1.6 million. The auction, which took place in Salem, offered property in the counties of Clatsop, Columbia, Coos, Crook, Deschutes, Douglas, Harney, and Malheur. High total bonus bids were made by Gulf Oil Corporation, Phillip Brock, A.G. Andrikopoulos, Marathon Oil Company, and Nahama and Weagant Energy Company. The high bid of $230 per acre bonus was made by Nahama and Weagant for a parcel of 640 acres in sec. 13, T. 7 N., R. 6 W.

Terms of State leases are as follows: 10-year duration, $1.00 per acre per year, and one-eighth (⅛) royalty. A drilling commitment within seven (7) years is also a stipulation of the leases.

An auction of mineral rights of Columbia County lands was held August 13, 1981, at the County Courthouse in St. Helens near Mist. Of a total of 65,330 acres offered, 50,025 acres were sold for a total of $1,528,504.00 cash bonus bids. Bids ranged from $0.25 to $93.00 per acre. Nahama and Weagant of Bakersfield, Calif., were successful bidders for the highest priced parcel, 600 acres at $93.00 per acre.

Diamond Shamrock completes drilling in Clatsop County

Diamond Shamrock Corporation has completed a three-well program in Clatsop County. The wells, drilled to depths of 7,864, 5,700, and 6,095 ft, are located near Knappa, Necanicum, and Saddle Mountain. All were abandoned as dry holes before reaching their projected depths. No further drilling plans for Clatsop County have been announced by Diamond Shamrock. The company, however, continues to remain active in the Mist field as partners with Reichhold Energy Corporation and Northwest Natural Gas Company.

Eighth producer completed at Mist

Reichhold Energy Corporation, in partnership with Diamond Shamrock Corporation and Oregon Natural Gas Development, has completed its eighth producing gas well in the Mist Gas Field. Located in sec. 1, T. 6 N., R. 5 W., approximately 2 mi north of the town of Mist, Columbia County 13-1 was completed August 17, 1981, flowing 2.6 million cubic feet of gas per day.

Plans are to connect this well to the Northwest Natural Gas pipeline that carries gas from the Mist field to Clatskanie. An offset well will also be drilled.

Exploration continues in Willamette Valley

American Quasar Petroleum Company's Kenneth Wetgen 26-32, NE ¼ sec. 26, T. 13 S., R. 4 W., Linn County, was spudded August 14, 1981. Proposed depth is 5,000 ft; the contractor is Paul Graham Drilling Company.

Quintana Petroleum Corporation's Gath 1, SE ¼ sec. 16, T. 8 S., R. 2 W., Marion County, was also spudded August 14, 1981. Proposed depth is 6,000 ft; the contractor is John Taylor Drilling Company. □

Newberry well is hottest geothermal prospect yet reported in Oregon

The hottest temperatures measured so far in a geothermal energy prospect in Oregon were reported July 23, 1981, by the U.S. Geological Survey (USGS), Department of the Interior.

USGS scientists said that a geothermal test hole being drilled in the summit crater of Newberry Volcano, about 25 mi southeast of Bend, Oreg., produced temperatures of 190°C (375°F) at a depth of 2,656 ft. A temperature of at least 150°C (300°F) is generally considered the minimum necessary for commercial consideration in using a geothermal resource to produce electricity.

Robert Tilling, chief, USGS Office of Geophysics and Geochemistry, emphasized that "the Newberry report is not yet a proven commercial discovery, but it is the most encouraging geothermal find in Oregon and could spur a re-evaluation of the nearby Cascade geothermal-energy potential. Finding a prospect as hot as the Newberry well provides at least the first step necessary to prove the feasibility of a geothermal resource—high temperatures. The next step would be to determine if there is enough flow to produce the volume and rate of the hot geothermal fluids that could be used in a power generation plant for conversion of the geothermal energy to electricity."

Edward Sammel, USGS hydrologist who is supervising the geothermal drilling at Newberry, said that plans are to drill the 3-in. hole to as deep as 3,000 ft and then run tests at that depth to determine temperature and rate of flow. The well is part of the USGS geothermal-research program that, in addition to other related efforts, is conducting a comprehensive regional evaluation of the geothermal potential of the Cascade Range in Washington, Oregon, and California.

The Newberry crater is in the Deschutes National Forest and is part of the "Newberry Caldera Known Geothermal Resource Area" (KGRA) previously outlined by the USGS. The U.S. Forest Service has been conducting an environmental impact study should any part of this KGRA ever be offered by the federal government for leasing for geothermal exploration.

Newberry Volcano is one of the largest volcanoes that formed in the conterminous 48 states during the geologically recent period of the last 2 million years (Quaternary Period). The last known eruption from the present Newberry Crater occurred about 1,400 years ago, and there is a high probability that extremely hot rock, perhaps even molten rock (magma), may still underlie the crater at fairly shallow depths.

The summit of Newberry Volcano has collapsed to form a caldera or crater about 5 mi in diameter. The collapse followed the eruption of vast volumes of volcanic ash and lava from the volcano's underlying magma chamber. Newberry Crater is similar in its origin to the crater formed by the violent eruption and associated collapse of nearby Mount Mazama about 6,700 years ago, whose caldera now contains scenic Crater Lake. Newberry Crater contains two small lakes, Paulina and East lakes.

Temperature measurements in the test hole were made by David Blackwell, Department of Geological Sciences, Southern Methodist University. USGS scientists said that in the lower 450 ft of the test hole, the temperature gradient became extremely high—about 600°C per kilometer, compared to a worldwide continental average of about 30°C per kilometer.

"This high gradient is extremely encouraging for two reasons," Tilling said. "First, it suggests an increased potential for development, should the high gradient continue at deeper depths. Second, and perhaps more important, the high gradient tends to confirm a theory that the low temperatures at shallow depths that have discouraged previous geothermal exploration in the nearby Cascade Range may reflect more the effects of shallow lateral flow of cool ground water rather than the real geothermal-energy potential. We think the high precipitation and generally high rate of ground-water recharge in the Pacific Northwest have combined to dilute and cool its geothermally heated water and to lower its rock temperatures at shallow depths during the past thousand years or so. As a result, temperature data from shallow drill holes in the past have tended to discourage additional geothermal development in the region. If temperatures remain high in the Newberry well, it could spur a re-evaluation of the geothermal energy potential in the Cascades."

Similar encouraging results were recently reported in the Canadian Cascades where a geothermal exploration project measured a temperature of more than 200°C in the Meagher Creek area of British Columbia. The recent eruptions of Mount St. Helens remain the most obvious manifestations of the internal heat and geothermal activity in the Cascade Range. □

Oregon fossils subject of new book

William N. Orr, professor of paleontology and geology at the University of Oregon, and Elizabeth L. Orr, catalog librarian, are the authors of a new 284-page paperback book, *Handbook of Oregon Plant and Animal Fossils.*

The book, which covers all aspects of Oregon plant and animal fossils, is divided into chapters on fossil plants, pollen, invertebrates, trace fossils, arthropods, freshwater fish, birds, marine vertebrates, and mammals and other land vertebrates. It contains drawings of fossils, lists of animal ranges, fossil-locality lists and maps, correlation charts, a 400-entry bibliography, and an index. The text reviews the literature on various fossils and discusses such paleontological subjects as ancient environments and settings, the forms in which fossils were preserved, and the ways fossils are used by geologists. The book is written for the knowledgeable layman but is also a useful reference for the professional geologist.

Price of *Handbook of Oregon Plant and Animal Fossils* is $10.95. It is available by mail from William N. or Elizabeth Orr, P.O. Box 5286, Eugene, OR 97405. □

(**New DOGAMI publications,** *from page 118)*
geologic mapping in Oregon, costs $7.00.

Open-File Reports 0-81-5, *Preliminary Geologic Map of the Amity and Mission Bottom Quadrangles, Oregon*, and 0-81-6, *Preliminary Geologic Map of the McMinnville and Dayton Quadrangles, Oregon*, begun in 1979 by H.G. Schlicker and completed in 1980 and 1981 by M.E. Brownfield, Oregon Department of Geology and Mineral Industries. These blackline preliminary geologic maps (scale 1:24,000) cover areas north and northwest of Salem in the northern Willamette Valley and represent DOGAMI's ongoing program to map strategic quadrangles in western Oregon that are, as in this case, experiencing rapid population growth. The maps delineate the geologic units and structure of the area and identify fossil and microfossil localities and abandoned oil and gas exploratory wells. Cost of each of these open-file reports is $4.00.

All of these new releases are available for inspection or purchase at the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. Payment must accompany orders of less than $20.00 □

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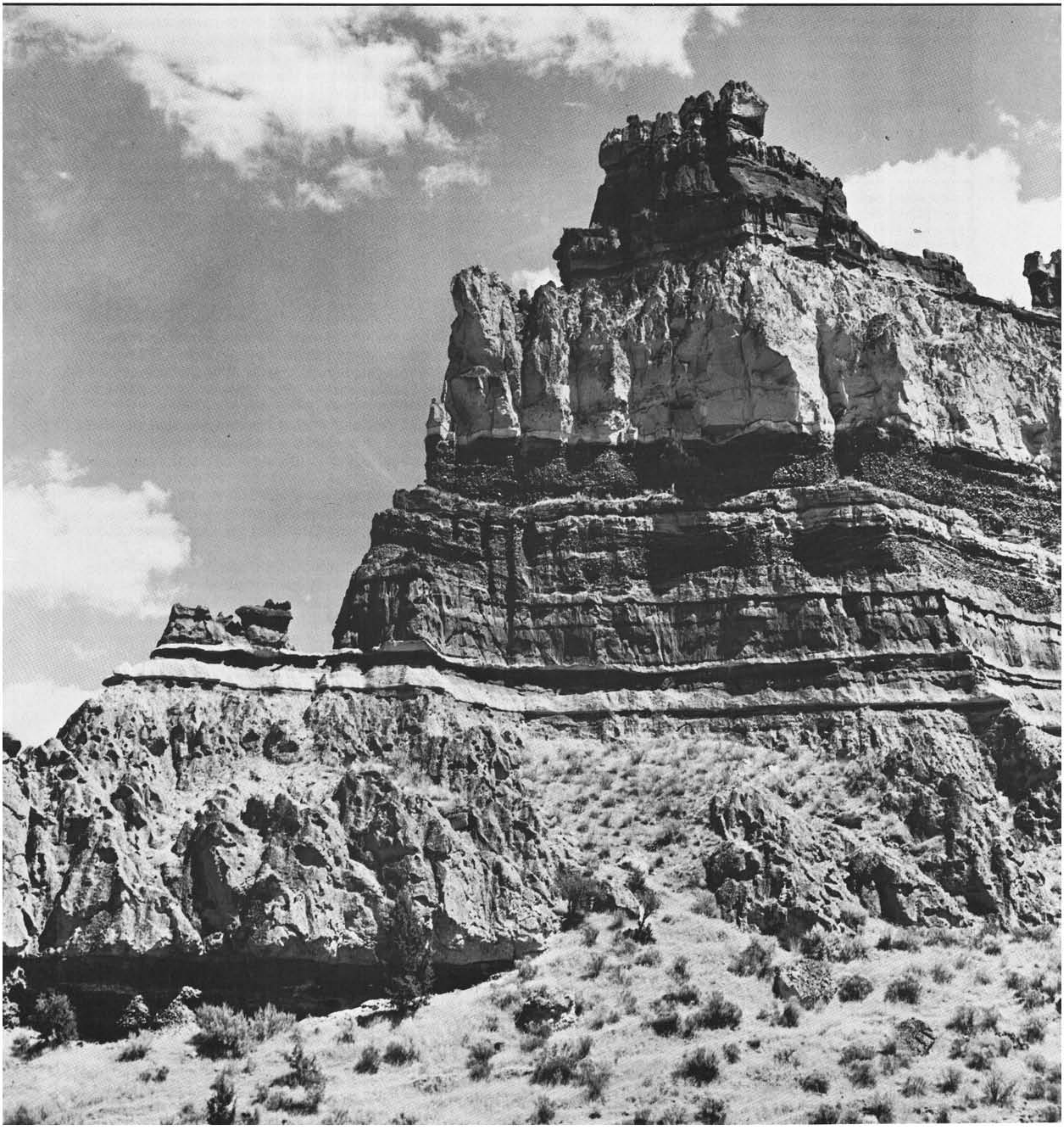

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COVER PHOTO

Part of the Deschutes Formation of the newly-defined Dalles Group exposed at the Island, Cove Palisades State Park, west of Madras, Oregon. Light-colored rocks are ash-flow tuffs, medium-gray unit at the base is a lahar, capping rock is a basalt, and dark units containing numerous small rounded rocks are gravel deposits. The Dalles Group and its five formations are discussed in the article beginning on the next page. Photo courtesy Oregon State Highway Division.

DOGAMI releases mid-Willamette Valley geologic maps

New five-color geologic maps for the mid-Willamette Valley between West Salem and Buena Vista have been released by the Oregon Department of Geology and Mineral Industries (DOGAMI).

The Department announces the publication of map set GMS-18 in its Geological Map Series, entitled *Geology of the Rickreall, Salem West, Monmouth, and Sidney 7½-minute Quadrangles, Marion, Polk, and Linn Counties, Oregon*, by DOGAMI Geologist James L. Bela.

The study area includes the area covered by the Salem 15-minute quadrangle and for these maps is divided into two sections; the northern portion is covered by the Rickreall and Salem West 7½-minute quadrangle maps, and the southern part by the Sidney and Monmouth 7½-minute quadrangle maps. The maps show thirteen surficial and bedrock geologic units, major lineaments, locations of abandoned oil and gas wells, and landslides.

Geologic map set GMS-18 is now available at the DOGAMI Office, 1005 State Office Building, Portland, OR 97201. The purchase price is $5.00. Payment must accompany orders of less than $20.00. □

Dallas Peck new Director of USGS

On September 18, 1981, the United States Senate confirmed the appointment of Dallas L. Peck as the new Director of the U.S. Geological Survey (USGS). With this action, Peck became the 11th Director of the 101-year-old USGS, succeeding H. William Menard, who resigned in January 1981.

Peck, 52, is a native of Cheney, Washington, and attended the public schools of Spokane, Washington. He received formal training in geology at California Institute of Technology (B.S. with honors, 1951, and M.S., 1953) and Harvard (Ph.D., 1960). He joined the USGS in 1951, and much of his career has been involved in geological and geothermal energy studies in the West, including field research at the USGS Hawaiian Volcano Observatory.

In 1977, Peck was named Chief Geologist and head of the USGS Geologic Division. Special assignments have included serving as U.S. member of special scientific delegations to the Soviet Union, Great Britain, Italy, Iceland, New Zealand, and Japan. Peck is the author of more than 50 scientific reports and publications; in recognition of his research efforts, he was awarded the Department of Interior's Meritorious Service Award in 1970. His leadership as Chief Geologist earned him the Department's highest award, the Distinguished Service Award, in 1979, and the Presidential Meritorious Executive Award in 1980. □

CONTENTS

Dalles Group: Neogene formations overlying the Columbia River Basalt Group in north-central Oregon

by Saleem M. Farooqui,[1] *John D. Beaulieu,*[2] *Russell C. Bunker,*[1] *Donald E. Stensland,*[3] *and Richard E. Thoms*[4]

Neogene sedimentary rocks lying above the Columbia River Basalt Group in north-central Oregon have been the subject of geologic study for over 100 years, including a full range of regional treatments, quadrangle maps, and detailed siting studies. The accumulated knowledge of this past work and the accelerated pace of geologic study in the area point to the need for a more coherent geologic synthesis of the Neogene deposits in order to improve communication, to enhance present understanding of the area, and to provide for more effective stratigraphic problem solving in the future.

Recently completed reconnaissance mapping (Farooqui and others, 1981) performed for Rockwell-Hanford Operations under contract to the U.S. Department of Energy provided a unique opportunity for the Oregon Department of Geology and Mineral Industries (DOGAMI) to develop the needed synthesis. The consistent stratigraphic framework arising from this effort is the basis for the formal establishment here of five formations and the elevation of the former Dalles Formation to group status.

—John D. Beaulieu, Deputy State Gologist, Oregon Department of Geology and Mineral Industries

ABSTRACT

Five discrete, mappable Miocene-Pliocene (Neogene) deposits occur north of the Blue Mountains in Oregon. Because these deposits have been variously mapped and referred to in the literature, conflicting and confusing nomenclature has developed. Using the lithologies, mappability, age and contact relationships, historic priorities and usage, and geographic separation of these deposits, we are formally defining five discrete formations: the Chenoweth, Tygh Valley, Deschutes, Alkali Canyon, and McKay Formations. Many of these formations have been mapped historically as the Dalles Formation, which we propose to raise to group rank. The Chenoweth, Tygh Valley, and Deschutes Formations contain chiefly volcaniclastic and volcanic rocks and are confined to The Dalles, Tygh, and Madras basins, respectively. The Alkali Canyon and McKay Formations contain chiefly epiclastic rocks and are confined to the Arlington and Agency basins, respectively.

The Dalles Group is middle Miocene to early Pliocene in age and overlies the Columbia River Basalt Group. The elevation of the Dalles Formation to a group status does not prejudge the situation outside the area of northeastern Oregon.

INTRODUCTION

In the literature the name Dalles Formation has been applied to indurated Neogene[5] epiclastic, pyroclastic, and volcaniclastic deposits and minor basalt flows overlying the Columbia River Basalt Group of Swanson and others (1979) in north-central Oregon on the north side of the Blue Mountains between the Cascade Range on the west and longitude 118° W. on the east. The deposits occur in geographically isolated basins (Figure 1), namely The Dalles, Tygh, Madras, Arlington, and Agency basins (Farooqui and others, 1981), that have developed chiefly in the Columbia River Basalt Group. The basins are defined by broad, flat-bottomed, singly or doubly plunging synclines that acted as depositional basins for the Neogene deposits. The Dalles, Tygh, and Madras basins are filled primarily with volcaniclastic sediment derived from the ancestral Cascade Range volcanoes. The Arlington and Agency basins are filled chiefly with epiclastic sediment derived from the northern flank of the Blue Mountains.

Although the deposits in these basins have been given many names, the Dalles Formation has been the name most commonly applied. Because the many names make present nomenclature confusing and stratigraphic interpretation unnecessarily difficult, we believe that a systematic rock-stratigraphic nomenclature is desirable. A recent assessment of the Neogene stratigraphy of north-central Oregon (Farooqui and others, 1981), coupled with previously published data, has allowed us to raise the Dalles Formation to group status and to formally assign five discrete formations to the group. This paper reviews the history of the Dalles Formation nomenclature, explains the basis for the revision in stratigraphic rank, and describes its constituent formations.

REVIEW OF STRATIGRAPHIC NOMENCLATURE

Condon's "Dalles Group" (Condon, 1874; Cope, 1880; and McCornack, 1928) was briefly studied by Knowlton (1902), Williams (1916), Collier (1916), Bretz (1917, 1921), and Buwalda and Moore (1929, 1930). Piper (1932) mapped the "Group" as the Dalles formation, suggesting it was approximately correlative with the Ellensburg formation of Smith (1903) and Mascall formation of Merriam (1901).

Newcomb (1966, 1969) formalized the Dalles Formation and extended it eastward from The Dalles to the Arlington area. He discarded the name "Shutler formation," which had been applied earlier to the supra-basalt deposits in the Arlington area (Hodge, 1941), because of its stratigraphic and lithologic ambiguity. Newcomb (1971) and Shannon and Wilson (1971, 1972, 1975a,b, 1981) demonstrated that the Dalles Formation overlies both the Columbia River Basalt Group and also the Rattlesnake and Selah members of the Ellensburg Formation of Schmincke (1964) where they project beyond the edges of overlying basalt flows of the Columbia River Basalt Group (Swanson and others, 1979). Because of lithologic similarities, Shannon and Wilson (1972) extended the Dalles

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[2] Oregon Department of Geology and Mineral Industries, Portland, Oregon.
[3] Southwestern Community College, Coos Bay, Oregon.
[4] Portland State University, Portland, Oregon.
[5] The Neogene includes the Miocene and Pliocene Epochs. Age assignment of the epoch boundaries is based on Berggren and van Couvering (1974), who revised the time boundaries between the Miocene-Pliocene and Pliocene-Pleistocene to 5.0 and 1.8 m.y., respectively. This revision, adopted by the U.S. Geological Survey (Sohl and Wright, 1978), is followed in this paper.

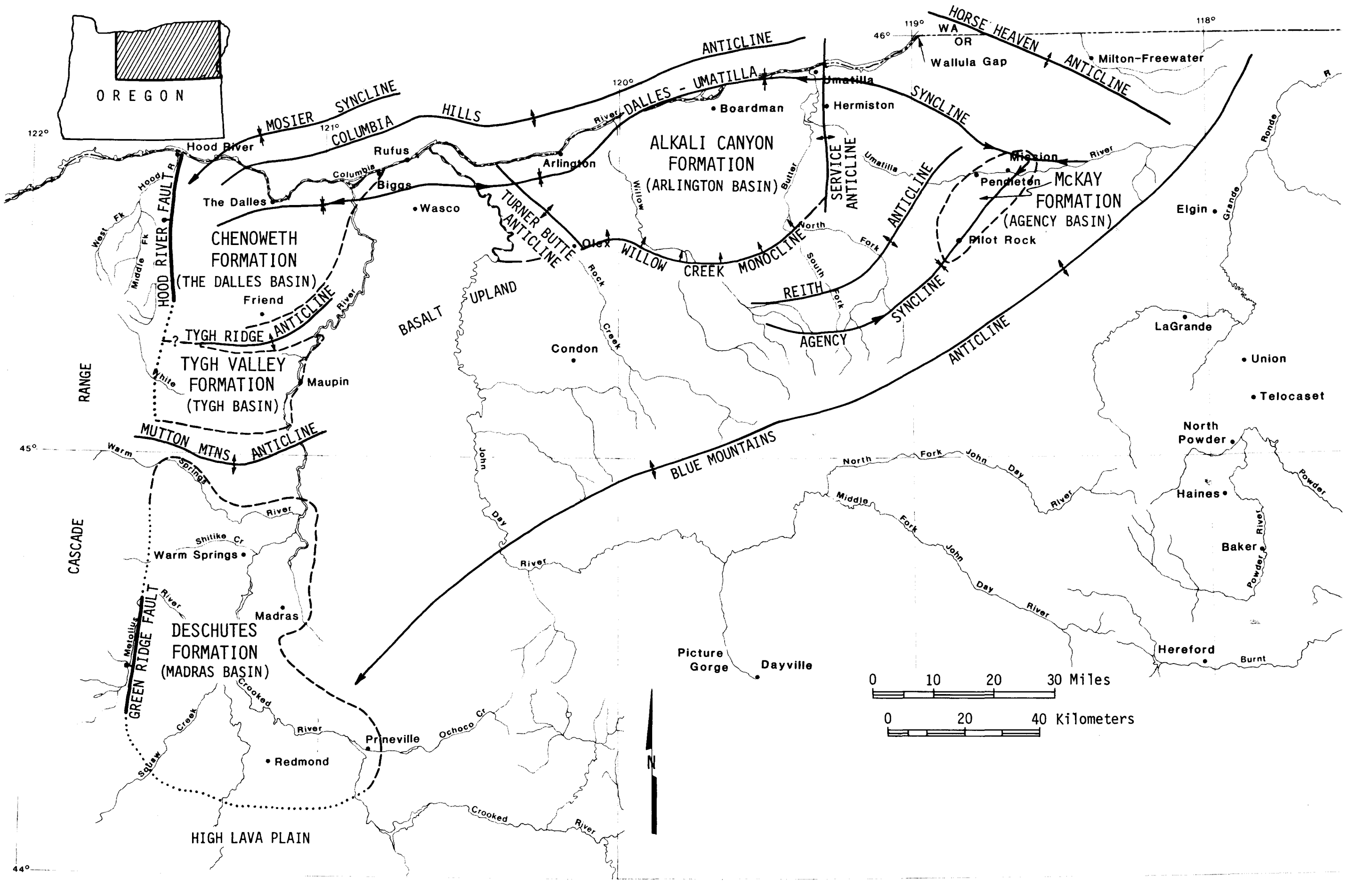

Figure 1. Generalized locations of the formations of the Dalles Group and their depositional basins.

Formation eastward from Arlington to the Boardman and Pendleton-Pilot Rock areas so as to include the fanglomerate of Hogenson (1964) and "McKay beds" of Shotwell (1956).

Hodge (1941) extended his Dalles formation south of The Dalles to latitude 44° N. He also mapped a fault sliver along the south flank of Tygh Ridge as John Day Formation. This sliver was mapped as part of the Mascall Formation by Wells and Peck (1961) and as Ellensburg Formation by Waters (1968b). Waters (1968a,b) also mapped the Dalles Formation in Tygh Valley and near Madras.

Use of the name Dalles in stratigraphic nomenclature for the Madras area has a history independent of that for the Dalles Formation at The Dalles and to the east. Russell (1905) called the heterogeneous assemblage of sediments, ash-flow tuffs, and lava flows exposed in the Deschutes and Crooked River Canyons the "Deschutes sands." Stearns (1930) termed these rocks the Deschutes formation. Hodge (1928, 1940) named similar rocks near Madras the Madras formation, but later (Hodge, 1942) called them Dalles formation. Williams (1957), Robinson and Price (1963), and Robinson and Stensland (1979) also used the name Madras Formation for these deposits, but Waters (1968a), Robinson (1975), and Robison and Laenen (1976) used the name Dalles Formation. Stensland (1970), Peterson and others (1976), and Taylor (1980) also used the name Deschutes Formation, citing its priority.

BASIS FOR REVISION OF STRATIGRAPHIC NOMENCLATURE

The Dalles Group is formally proposed for stratigraphic units in Oregon historically referred to as the Dalles Formation that either overlie the Columbia River Basalt Group or can be demonstrated laterally to overlie it. This name conforms to the provisions of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1970), does not prejudge the situation outside the area, and follows many decades of work in Oregon.

Data now are sufficient to elevate the Dalles Formation formally to group status and to identify its constituent units (formerly, in part, collectively termed the Dalles Formation) as related but distinctly mappable formations. Each formation is sufficiently unique to permit its mapping as a geographically discrete unit. The Dalles Group is confined to The Dalles, Arlington, Boardman, Pendleton, Pilot Rock, Tygh Valley, Madras, and Redmond areas, where the name Dalles was used previously.

The Dalles Group is characterized as follows:

1. The Dalles Group is composed of five discrete, mappable formations. Some of the formations may originally have graded locally into one another; these contacts, if they are preserved, are chiefly buried beneath younger volcanic rocks.
2. The formations of the Dalles Group are mappable units and have been treated extensively as such in the literature.
3. The formations overlie the Columbia River Basalt Group by definition. Contacts with the basalt are sharp and well defined. Where flows in the Columbia River Basalt Group overlie interbeds of the Ellensburg Formation, those interbeds and their mappable extensions beyond the basalt pile are *not* considered part of the Dalles Group.

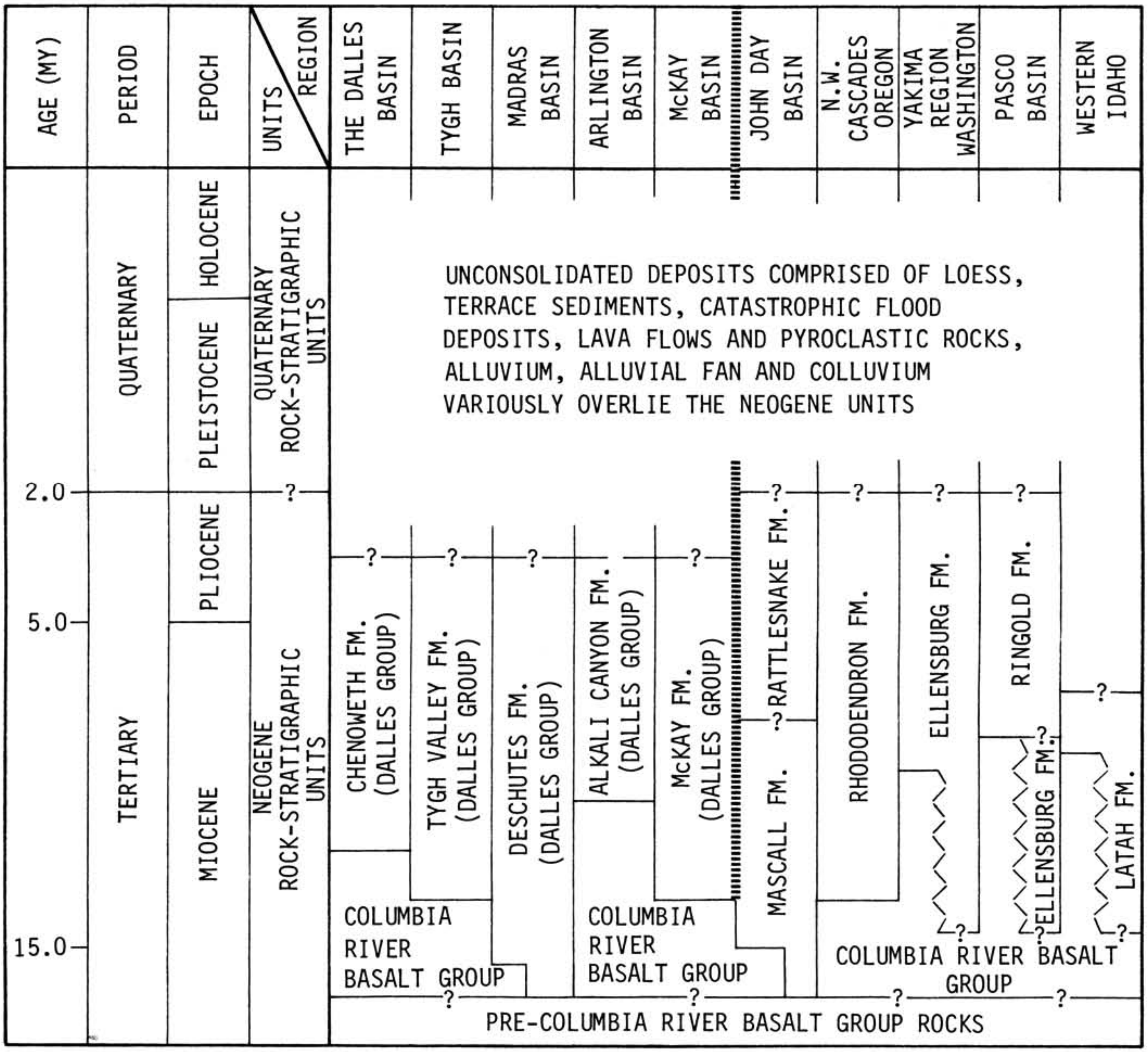

Figure 2. Regional correlation chart of the Dalles Group.

4. The group is overlain by a variety of Quaternary deposits. Because contacts with these deposits may be either sharp or gradational, they are defined for each formation. The gradational contacts are based on lithologic criteria that provide the greatest utility in mapping. The Quaternary units are excluded from the underlying formations.
5. All five formations are of middle(?) Miocene to Pliocene age.

In using the name Dalles, historic priorities and popular usage of older nomenclature are maintained. Further, the name Dalles Group is applied only to those units for which the name Dalles Formation has been used previously. It is not the intent to extend the name Dalles Group into other areas containing analogous rocks for which other terminology may be in common usage.

The five formations of the Dalles Group are the Chenoweth, Tygh Valley, Deschutes, Alkali Canyon, and McKay Formations. The locations of these formations are shown in Figure 1; their regional stratigraphic correlations are presented in Figure 2. The formations are described in the following sections.

CHENOWETH FORMATION

Indurated volcaniclastic deposits overlying the Columbia River Basalt Group in The Dalles area are herein formally named the Chenoweth Formation of the Dalles Group. The name Chenoweth comes from Chenoweth Creek (T. 2 N., R. 13 E.), which is just west of The Dalles, Wasco County, Oregon. The formation was previously mapped as the Dalles Formation (Condon, 1874; Cope, 1880; Piper, 1932; Newcomb, 1966, 1969).

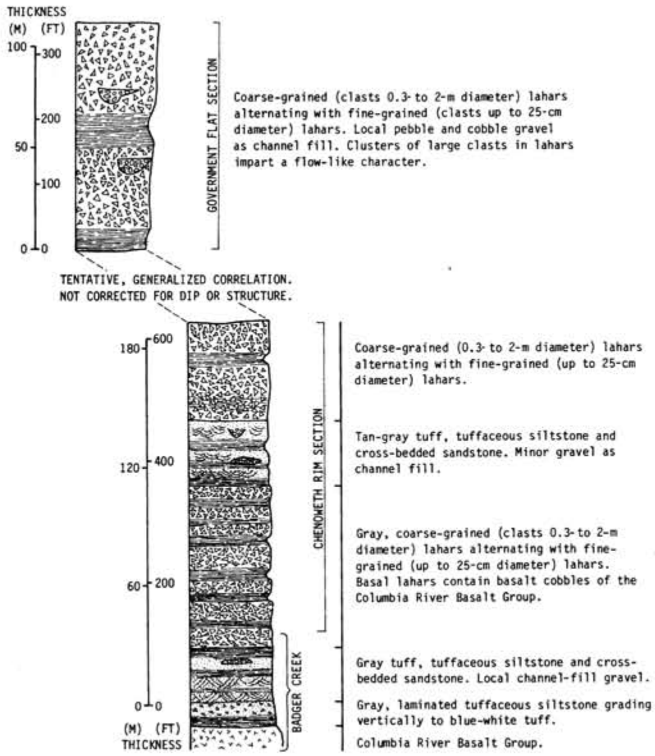

Figure 3. Reference sections of the Chenoweth Formation. Locations: Badger Creek and Chenoweth Rim sections in NE¼ sec. 30, T. 2 N., R. 13 E.; Government Flat section in NE¼ sec. 10, T. 1 N., R. 12 E.

The Chenoweth Formation is confined to The Dalles basin, which consists of two broad, flat-bottomed synclines, The Dalles-Umatilla and the Mosier synclines. The Ortley anticline separates the Mosier and The Dalles-Umatilla synclines, but it plunges southwestward, thereby allowing the connection of the Chenoweth Formation between the two synclines. The basin is bordered by the Columbia Hills anticline to the north in Washington, by the Cascade Range to the west, by the Tygh Ridge anticline to the south, and by the basalt upland to the east of the Deschutes River (Figure 1).

The formation is an eastward-spreading volcaniclastic debris fan consisting of interbedded agglomerate; tuff breccia; pumiceous lapilli tuff; lithic lapilli tuff; andesitic and basaltic conglomerate and sandstone; tuffaceous sandstone, siltstone, and clay shale; and minor basalt flows. The tuff breccia commonly consists of angular andesite clasts, 2 to 10 cm in diameter, isolated in a tuff matrix. The agglomerate consists of large, angular, boulder- and cobble-sized andesite clasts in a sandy tuffaceous matrix. The tuff breccia and agglomerate are interpreted to be lahar deposits owing in part to their common occurrence in lenticular channels and in sheets. The other rock types commonly are thick or lenticularly bedded. Beds are commonly less than 1 m thick and laterally discontinuous, exhibiting abrupt lithofacies changes. The formation also contains a 15-m-thick interbedded basalt flow along Fulton Ridge (Tps. 1 and 2 N., Rs. 14 and 15 E.; Newcomb, 1969). Figure 3 shows the reference sections of the Chenoweth Formation. Because abrupt lithofacies changes are common, no single section is entirely representative of the formation. Therefore, reference sections, rather than a type section, are designated.

Lahars and interbedded conglomerate and sandstone rich in andesite clasts dominate the western part of the formation near the foothills of the Cascade Range. Farther northward and eastward, the proportion of lahars decreases, while "normal" fluvial deposits of conglomerate, sandstone, and siltstone become more common. Newcomb (1969) interpreted the formation as consisting of a proximal "volcanic-sedimentary" debris fan deposit that changes distally to a "sedimentary" deposit. The source area for the volcanic sediment lies toward the Cascade Range, but its precise location is uncertain. Because the Chenoweth Formation is overlain by andesite flows toward the Cascade Range, it cannot be easily traced to its source.

Newcomb (1969) reported a total thickness of approximately 550 m for the "volcanic-sedimentary" facies, noting that thicknesses decrease distally to approximately 137 m near the Deschutes River and to 30 m north of the Columbia River. Piper (1932) reported thicknesses of 275 m (sec. 28, T. 1 N., R. 12 E.) and 198 m (sec. 29, T. 2 N., R. 13 E.).

The Chenoweth Formation lies upon the Priest Rapids and Frenchman Springs Members of the Columbia River Basalt Group (Swanson and others, 1981). Generally south of latitude 44°33′ N., it overlies the Frenchman Springs Member. The Chenoweth Formation is locally overlain by Quaternary loess near the Columbia River. The loess is distinguishable from tuffaceous siltstone of the Chenoweth Formation by its relatively nonindurated state and lack of stones. Southwest of The Dalles, Quaternary(?) intracanyon basalt lies in the valleys of Fivemile Creek and the South Fork of Mill Creek, both of which are cut into the Chenoweth Formation. To the west, andesite lavas of the Cascade Range overlie the formation.

The Chenoweth Formation is of late Miocene to early Pliocene(?) age, as indicated by K/Ar and paleontologic age determinations. Buwalda and Moore (1930) dated vertebrates in the formation as early Pliocene. These paleontologic ages are uncorrected with respect to Berggren and van Couvering's (1974) epoch boundaries but are now considered to be most likely Miocene age. K/Ar dates reported by Farooqui and others (1981) are 5.1 ± 0.5, 5.7 ± 0.6, and 7.5 ± 0.7 m.y.

TYGH VALLEY FORMATION

Indurated epiclastic and volcaniclastic deposits and basalt flows overlying the Columbia River Basalt Group in the Tygh Valley-Juniper Flat area are herein formally named the Tygh Valley Formation of the Dalles Group. The name Tygh Valley comes from the town of Tygh Valley (sec. 3, T. 4 S., R. 13 E.) in Wasco County, Oregon. The formation was earlier mapped as the Dalles and John Day formations (Hodge, 1941), the Dalles and the Mascall formations (Wells and Peck, 1961), and the Dalles and the Ellensburg Formations (Waters, 1968b). We include also the olivine basalt of Waters (1968b) in the Tygh Valley Formation.

The Tygh Valley Formation is confined to the Tygh basin, which consists of a broad, flat-bottomed, west-plunging syncline. The basin is bordered by the Tygh Ridge anticline to the north, the Cascade Range to the west, the Mutton Mountains to the south, and the basalt upland to the east of the Deschutes River (Figure 1).

The epiclastic and volcaniclastic rocks of the formation consist of weakly cemented basaltic, andesitic, and pumiceous sandstone and conglomerate; tuffaceous siltstone and sandstone; tuff; pumice lapilli tuff; tuff breccia; and agglomerate. The tuff breccia and agglomerate, which are similar to those in the Chenoweth Formation, are also interpreted as lahar deposits. Beds are lenticular and 1 to 20 m thick.

Because abrupt horizontal and vertical lithofacies changes are common, no single section is entirely representative of the formation, and no type section is designated. One reference section near Tygh Valley, however, is reasonably represen-

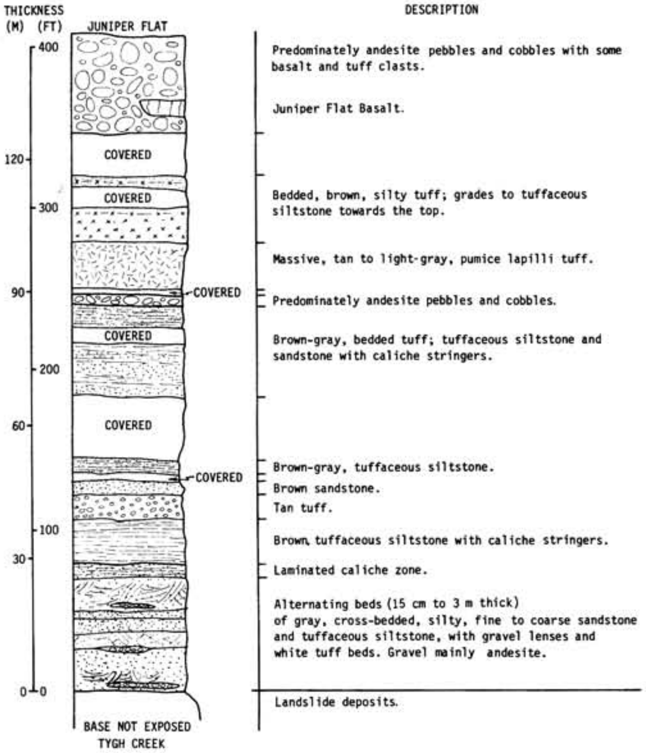

Figure 4. Reference section of the Tygh Valley Formation. Location: North-facing roadcut along Tygh Valley-Wamic road, sec. 4, T. 4 S., R. 13 E.

tative of the heterogeneity of the Tygh Valley Formation (Figure 4). Here it consists of interbedded siltstone, sandstone, conglomerate, tuff, and a basalt flow. The basalt, the "Juniper Flat basalt" (olivine basalt of Waters, 1968b), is discontinuous at this section and appears to be interbedded with gravel. Westward up Badger Creek and northwestward up Tygh and Jordan Creeks, the "Juniper Flat basalt" is overlain by andesite-rich lahars that pass upward into andesite lavas. These andesite lavas were separated by Farooqui and others (1981) from the Tygh Valley Formation, but the contact between them and the formation is approximate. The contact may be gradational; westward thickening of the lavas and concomitant thinning of sediment suggests interbedding of lavas with sediment. Trimble (1963) and Taylor (1980) reported similar relations for the Rhododendron and Deschutes Formations, respectively.

The exact contact between the Tygh Valley Formation and the Chenoweth Formation is difficult to locate precisely. The Tygh Valley Formation is generally distinguished from the Chenoweth Formation by its separate location and paucity of lahars. On the western end of Tygh Ridge, south of the former hamlet of Friend, andesite-rich lahars typical of the Chenoweth Formation overlie basalt inferred to be the "Juniper Flat basalt." This may suggest that the upper part of the Chenoweth Formation or its equivalent may overlie the Tygh Valley Formation (Farooqui and others, 1981). Final resolution awaits more detailed mapping.

The Tygh Valley Formation lies disconformably on the Frenchman Springs Member along the northern edge of the Tygh basin and on the Grande Ronde Basalt of the Columbia River Basalt Group along the southern edge of the basin (Swanson and others, 1981). It is overlain by Miocene-Pliocene andesite flows of the Cascade Range.

The Tygh Valley Formation is of middle Miocene to Pliocene age because it overlies the approximately 14-m.y.-old Frenchman Springs Member (McKee and others, 1977) and includes basalt and tuff dated at 7.5 ± 0.8 and 4.9 ± 0.5 m.y., respectively (Farooqui and others, 1981).

DESCHUTES FORMATION

Russell (1905) called the heterogeneous assemblage of interbedded volcanic, volcaniclastic, pyroclastic, and epiclastic rocks exposed in the Deschutes and Crooked River Canyons in the Prineville-Redmond-Madras-Warm Springs area the "Deschutes sand." Since then, these deposits were variously mapped as the Deschutes Formation (Stearns, 1930; Hodge, 1942; Peterson and others, 1976; Stensland, 1970; Taylor, 1980), the Madras formation (Hodge, 1928, 1940; Williams, 1957; Robinson and Price, 1963; Robinson and Stensland, 1979), and Dalles Formation (Hodge, 1942; Waters, 1968a; Robinson, 1975; Robison and Laenen, 1976). To remove the confusion in the nomenclature, we herein formally restore the name Deschutes Formation because of its historic priority and because of excellent exposures of the unit along the Deschutes River. We assign the formation to the Dalles Group.

The Deschutes Formation occurs in the geographically isolated Madras basin, which consists of several broad synclines developed on the southwest-plunging Blue Mountains anticline. The boundaries of the basin are defined by the Mutton Mountains to the north, the Cascade Range to the west, the High Lava Plains to the south, and Blue and Ochoco Mountains to the east (Figure 1).

Stensland (1970) provided detailed information on the Deschutes Formation. It consists of epiclastic and pyroclastic sedimentary rocks; welded and nonwelded ash-flow tuff; interbedded, intracanyon, and plateau-forming basalt flows; basaltic intrusions and cinder cones; diatomite; and mudflow deposits. The rock types are complexly interbedded, resulting in abrupt lithofacies changes. Individual units are commonly

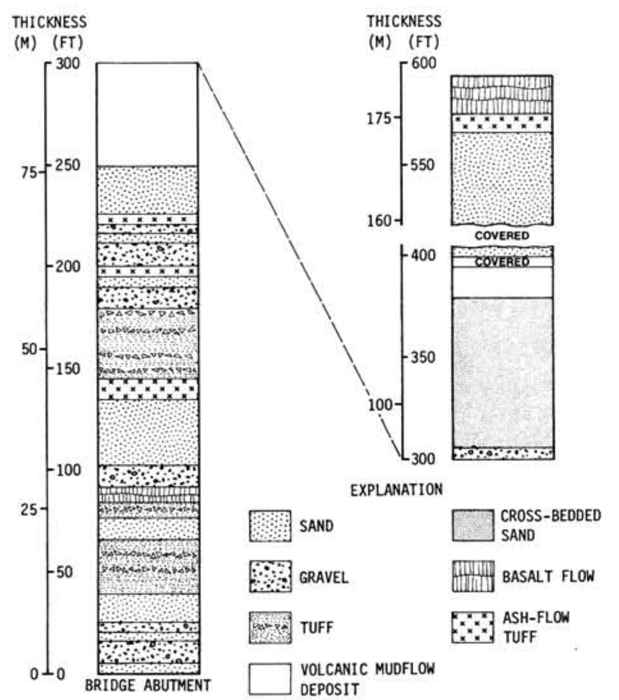

Figure 5. Reference section of the Deschutes Formation. Location: Roadcut on west side of Lake Billy Chinook, secs. 16 and 21, T. 12 S., R. 12 E.

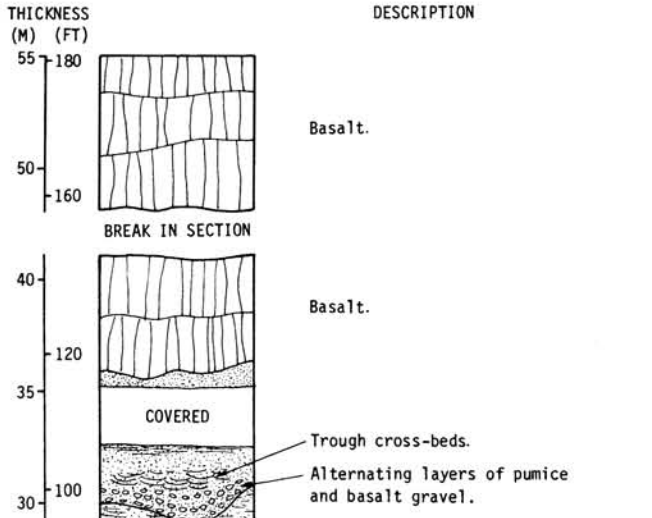

Figure 6. Reference section of the Deschutes Formation. Location: SW¼ sec. 16, E½ sec. 17, T. 9 S., R. 12 E. along U.S. Highway 26.

lenticular, wedge shaped, and 1 to 20 m thick. Lateral continuity is poor, except for the basalt flows and ash-flow tuffs. The sedimentary deposits are particularly varied. They consist of basaltic sandstone and conglomerate, pumice gravel, and tuffaceous siltstone and sandstone. Vitric ash, cindery ash, lapilli, pumice lapilli, and volcanic breccia also are common. Because abrupt lithofacies changes are common, no single section is entirely representative of the formation. Therefore, two reference sections, rather than a type section, of the Deschutes Formation are presented in Figures 5 and 6.

Thickness of the Deschutes Formation varies. Stensland (1970) reported thicknesses of less than 30 m to as much as 240 m, noting that the formation wedges out against hills eroded in older rocks. Hodge (1940) reported a thickness of 300 m near Warm Springs. The reference sections at Lake Billy Chinook (Figure 5) and northwest of Warm Springs (Figure 6) are 190 m and 55 m thick, respectively.

The Deschutes Formation is unconformable on the John Day and Clarno Formations and on the Grande Ronde(?) Basalt of the Columbia River Basalt Group, but it does not interfinger with the Columbia River Basalt Group. The Deschutes Formation is locally overlain by Quaternary deposits and lava flows. Near the Cascade Range, the formation is overlain by andesite flows and by andesite and basalt gravel.

The Deschutes Formation is of middle Miocene to early Pliocene age. Chaney (1938, 1944, 1959) described its flora as early to middle Pliocene. Evernden and James (1964) reported K/Ar dates of 4.3 and 5.3 m.y., and Armstrong and others (1975) reported K/Ar dates of 4.9 ± 0.5, 5.8 ± 1.0, and 15.9 ± 3.0 m.y. Dates for plateau-forming basalts in the Deschutes Formation are 8.9 ± 1.0 and 10.7 ± 1.2 m.y.; one interbedded basalt flow is 13.2 ± 1.5 m.y. (Farooqui and others, 1981). Except for the 15.9-m.y. date, these dates place the Deschutes Formation in the middle Miocene to early Pliocene.

ALKALI CANYON FORMATION

Indurated epiclastic deposits overlying the Columbia River Basalt Group in the Arlington-Boardman area are herein formally named the Alkali Canyon Formation of the Dalles Group. The name comes from Alkali Canyon (T. 2 N., Rs. 20 and 21 E.), 16 km southwest of Arlington, Gilliam County, Oregon. The formation was previously named the "Alkali lake beds" (Hodge, 1932); the "Shutler formation" (Hodge, 1941, 1942); fanglomerate (Hogenson, 1964); Dalles Formation (Newcomb, 1969, 1971a; Shannon and Wilson, 1971, 1972, 1973, 1975a,b, 1981; Farooqui, 1980); and Tertiary sedimentary rocks (Walker, 1973).

The Alkali Canyon Formation occurs only in the Arlington basin, which consists of the broad, flat-bottomed, doubly plunging Dalles-Umatilla syncline. The basin is bordered by the Columbia Hills anticline on the north, the Service anticline to the east, the Blue Mountains to the south, and basalt upland to the west (Figure 1).

The Alkali Canyon Formation is composed of basalt gravel and tuffaceous sediment. Because rapid lithofacies changes are common, no single section is entirely representative of the formation, and a reference section, rather than a type section, is designated. The reference section is in Alkali Canyon (Figure 7), where the basal Alkali Canyon Formation is a 5-m-thick, light-gray vitric tuff overlying the Selah member of the Ellensburg Formation (Newcomb, 1971). This vitric tuff is here assigned to the Alkali Canyon Formation. Newcomb (1971) tentatively assigned it to his Dalles Formation, noting its presence above the Pomona Member (Columbia River Basalt Group). This relation is confirmed by subsurface data (Shannon and Wilson, 1981). North of Alkali Canyon, the vitric tuff underlies much of the Chem-Security Systems waste disposal site but extends westward only as far as the W¼ sec. 25, T. 3 N., R. 20 E. (Shannon and Wilson, 1971, 1981).

The vitric tuff is overlain at this section by 2 to 3 m of tan, iron-stained, carbonate-veined, tuffaceous silty clay. The upper surface of the silty clay is scoured into channels up to 2 m wide and deep that are filled with basalt gravel and that comprise the 3-m-thick middle part of the section. East of this section, along the northern wall of Alkali Canyon, the middle part is 6 to 15 m thick (Newcomb, 1971). In the reference section, the gravel is partly carbonate-cemented, ranging from granules to small boulders, with cobbles most common. Locally a sand matrix partly fills interstices among the clasts; elsewhere the gravel is openwork. Tuffaceous, micaceous,

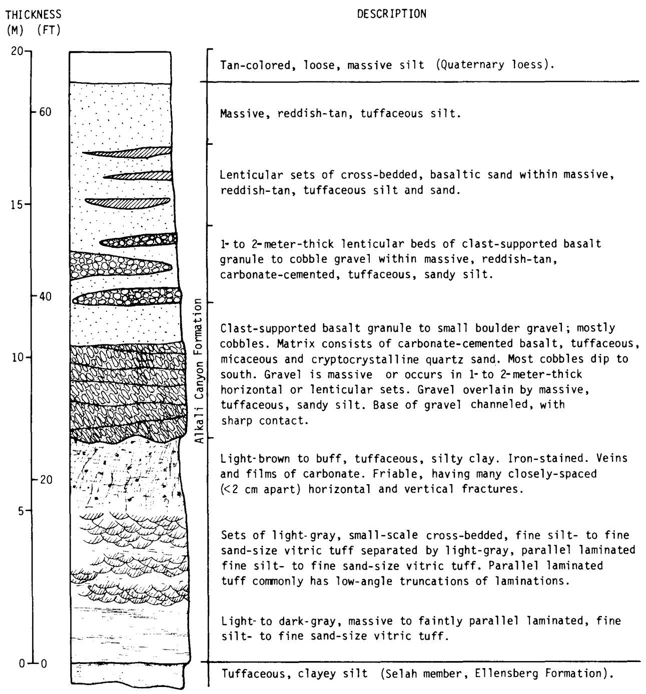

Figure 7. Reference section of the Alkali Canyon Formation. Location: Chem-Security Systems site access road, SE¼ sec. 25, T. 2 N., R. 20 E.

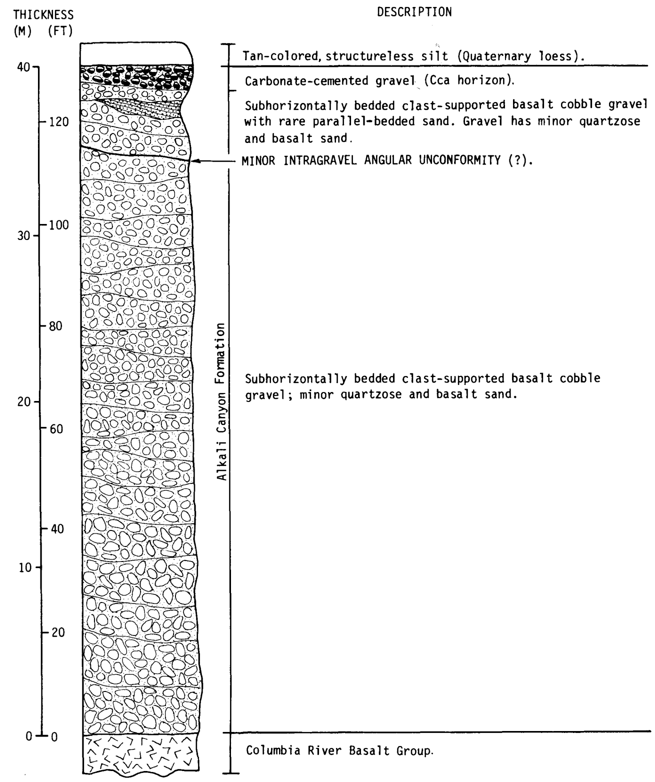

Figure 8. Reference section of the Alkali Canyon Formation. Location: NW¼ NW¼ sec. 21, T. 1 S., R. 21 E. Below the unconformity (?), beds trend N. 10° W. to N. 50° E.; apparent dips are 40° to 60° W. Above the unconformity (?), beds trend N. 10° E.; apparent dip is 10° W.

cryptocrystalline-quartz sands comprise the matrix. The gravel is commonly massive, but 1-m-thick horizontal and lenticular beds also occur. The cobbles commonly dip southward, indicating a general northward transport direction.

The upper 10 m of this section is comprised of red-tan, carbonate-cemented, tuffaceous sandy silt. The lower 3 m consists of sandy silt interbedded with 1- to 2-m-thick, lenticular, cross-stratified gravel beds. Lenticular sets of cross-bedded basaltic sand isolated in sandy silt generally comprise the middle part of this 10-m-thick upper section. The uppermost 2 to 3 m of section consists of loose to compact, massive tuffaceous silt.

The four-fold division of the Alkali Canyon Formation occurs only locally. Another section near Olex (Figure 8) consists entirely of basalt-cobble gravel in a quartzose and basaltic sand matrix. There the Alkali Canyon Formation rests directly on the Frenchman Springs Member of the Columbia River Basalt Group.

Other exposures and subsurface data reveal more diversity within the Alkali Canyon Formation (Shannon and Wilson, 1975a,b). Gravel pit exposures commonly display horizontal, 1- to 2-m-thick beds of massive and cross-stratified cobble gravel. The cobbles show southward-dipping imbrication, indicating general northward transport. Tuffaceous sand and silt lenses are interbedded with and truncated by the gravel beds. Temporary exposures in trench walls at the Chem-Security Systems site (sec. 25, T. 3 N., R. 20 E.) revealed a lenticular, 1-m-thick clay bed overlying the gravel near the top of the formation. The clay is thinly laminated and interbedded with a thin, vitric tuff bed. Gravel overlies the clay and tuff.

The depositional environment of the Alkali Canyon Formation is poorly understood. Hogenson (1964) interpreted it as fanglomerate. The assemblage of bedding types, sedimentary structures, and coarse grain sizes, together with general northward transport direction and the proximity of the Blue Mountains, suggests that the deposits represent the "proximal braided stream" type of deposit described by Rust (1978). However, local alluvial fans also constitute part of the depositional system of the Alkali Canyon Formation (Farooqui and others, 1981).

Regionally, the Alkali Canyon Formation lies both disconformably and unconformably on the Elephant Mountain, Pomona, Priest Rapids, and Frenchman Springs Members of the Columbia River Basalt Group. It also locally overlies the Rattlesnake and Selah members of the Ellensburg Formation. A slight angular unconformity is present where the Alkali Canyon Formation overlies the edges of the basalt members (Newcomb, 1971; Shannon and Wilson, 1971, 1973, 1975a,b, 1981).

Our investigations support previous work by Newcomb (1971), Shannon and Wilson (1972, 1975a,b), and Kent (1978) indicating that the Alkali Canyon Formation is a post-Columbia River basalt unit but that it does not interfinger with it, as do interbeds of the Ellensburg Formation.

The Alkali Canyon Formation is of late Miocene to early Pliocene(?) age, based on vertebrate fossils assigned to the Hemphillian by Shotwell (1956). According to Berggren and van Couvering (1974), the Hemphillian is late Miocene to early Pliocene in age. The Alkali Canyon Formation is not older than late Miocene, however, because it overlies the 10.5-m.y.-old (McKee and others, 1977) Elephant Mountain Member of the Columbia River Basalt Group (Shannon and Wilson, 1975b).

McKAY FORMATION

Indurated sedimentary deposits overlying the Columbia River Basalt Group in the Pendleton-Pilot Rock area are herein formally named the McKay Formation of the Dalles Group. The name McKay comes from McKay Reservoir (T. 1 N., R. 32 E.) in Umatilla County, Oregon. The formation was earlier named "McKay beds" (Shotwell, 1956), fanglomerate (Hogenson, 1964), Dalles Formation (Shannon and Wilson, 1972; Gonthier and Harris, 1977; Farooqui, 1980), and Tertiary sedimentary rocks (Walker, 1973).

The McKay Formation occurs only in the Agency basin. The basin is defined by the doubly-plunging, flat-bottomed Agency syncline, which is geographically separated from other nearby basins by the Blue Mountains, Reith, and Horse Heaven anticlines (Figure 1).

The McKay Formation is composed of partially cemented basalt gravel and interbedded tuffaceous sand and silt. Because abrupt lithofacies changes are common, no single section is entirely representative of the formation, and reference sections, rather than a type section, are designated. Reference sections of the formation are near McKay Reservoir (Figure 9) and Mission (Figure 10). The McKay Reservoir section (Figure 9) consists of dense, aphyric basalt gravel and less common cobbles and small boulders of red vesicular basalt. The gravel contains an estimated 10 percent sand-silt matrix, ranging from very coarse sand to silt. The matrix is commonly carbonate cemented, with the very coarse to fine sand fraction composed of subrounded to angular basalt grains and the finer matrix of carbonate "nodules" and quartzose fine sand to silt. Rare sand-silt lenses fill depressions atop gravel beds in the lower half of the section. The silt is quartzose; the sand is mostly basaltic. Gravel beds overlie these sand-silt lenses along irregularly scoured contacts. In the interval from between approximately 40 to 43 m above its base, the section consists of lenticular, 0.5-m-thick sand beds. The sand beds are weakly carbonate cemented and iron stained. They interfinger with .5- to 10-cm-thick lenticular pebble layers. The sand beds are overlain by approximately 2 m of tuff. The upper surface of the tuff is channeled and is overlain by cobble gravel that contains several boulders of calichified silt.

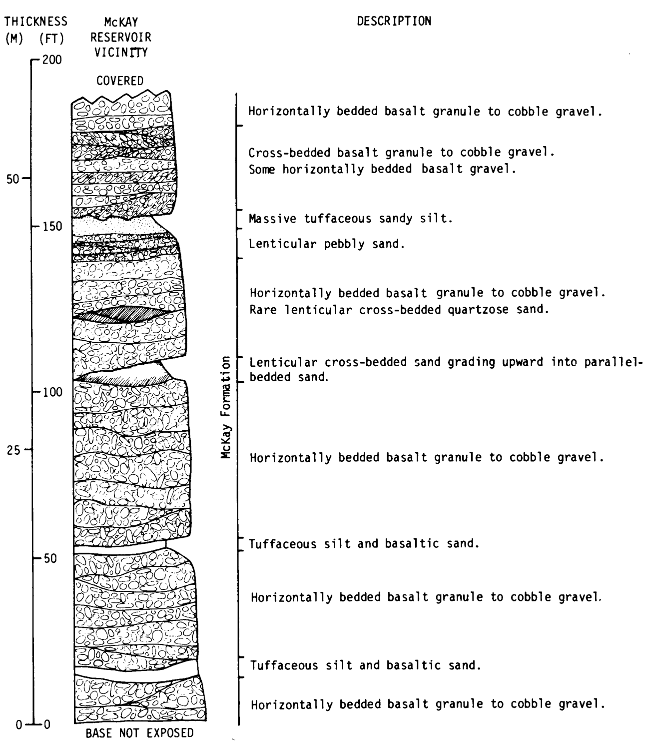

Figure 9. Reference section of the McKay Formation. Location: E¼ sec. 33, T. 2 N., R. 32 E.

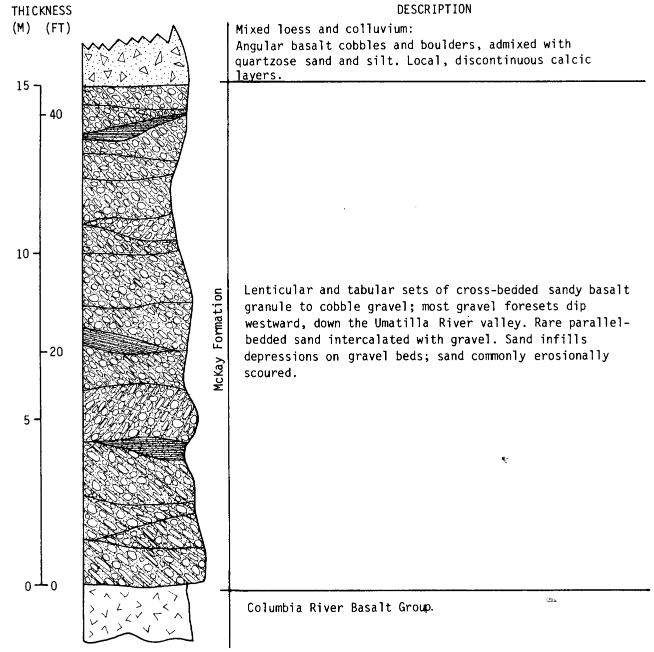

Figure 10. Reference section of the McKay Formation. Location: North-facing roadcut, NW¼ NE¼ NE¼ sec. 12, T. 2 N., R. 32 E.

The Mission section (Figure 10) consists of 0.5- to 1-m-thick lenticular cosets of cross-stratified sandy basalt granule to cobble gravel. A minor sand matrix coats the gravel; however, most gravel is openwork. The cross-bedding dips westward.

The McKay Formation was earlier mapped by Hogenson (1964) as fanglomerate; however, it may, in part, be a valley-fill deposit. The thickest observed sections are in or near the Birch-McKay Creek and Umatilla River valleys. Away from these valleys, the McKay Formation thins rapidly, suggesting it was deposited within the ancestral valleys of these streams.

Thickness of the McKay Formation varies. The McKay Reservoir section, whose base is not exposed, is 55 m thick. The Mission section is estimated to be 15 m thick. The McKay Formation disappears or thins to 2 to 5 m within 5 km west of Birch Creek. Well logs (Gonthier and Harris, 1977) show it is 4 to 77 m thick between McKay Creek and the Blue Mountains.

The McKay Formation is conformable atop the Frenchman Springs Member and Grande Ronde Basalt of the Columbia River Basalt Group (Swanson and others, 1981) within the Agency syncline. An angular unconformity between it and the basalt, however, can be inferred where horizontal beds of the McKay Formation are adjacent to the flanks of the bordering Blue Mountain, Reith, and Horse Heaven anticlines. At its upper contact, the McKay Formation is overlain by Quaternary loess; however, this contact is commonly difficult to locate precisely because gravel-free tuffaceous silt in the upper McKay Formation is similar to, and underlies, the loess. Because 0.5 to 1 m of loess commonly overlies basalt outcrops near the McKay Formation, this loess thickness was used locally to approximately locate the contact between loess and silt of the underlying McKay Formation.

The McKay Formation is of late Miocene to early Pliocene age. Shotwell (1956) described its fauna as Hemphillian. Based on Berggren and van Couvering's (1974) chronology, the Hemphillian was approximately from 10 to 4.5 m.y. or late

Miocene to early Pliocene. The formation is not older than middle Miocene, however, because it overlies the approximately 14-m.y.-old Frenchman Springs Member of the Columbia River Basalt Group.

ACKNOWLEDGMENTS

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Plate-tectonic maps of Circum-Pacific region available from AAPG

Three new plate-tectonic maps of the Circum-Pacific region have just been published by the American Association of Petroleum Geologists (AAPG). The full-color maps of the Northwest, Northeast, and Southeast Quadrants depict active plate boundaries, plate-motion vectors, major intraplate faults, seismic epicenters, Holocene volcanic activity, and magnetic lineations. Accretionary terrane along the Pacific rim, including the coast of western United States, Canada, and Mexico, is shown on the Northeast map sheet. The final two maps in this 1:10,000,000 series, the Southwest and Antarctica sheets, are scheduled for publication this year.

The basic Circum-Pacific Map Series consists of five 1:10,000,000 scale maps and a basin-wide map at a scale of 1:20,000,000. Additional thematic maps now under preparation include the Geologic, Tectonic, Energy Resources, Mineral Resources, and Geodynamics Series.

The plate-tectonic maps are available from the AAPG Bookstore, P.O. Box 979, Tulsa, OK 74101, at $8.00 each. Also available are full-color geographic maps at $12.00 each or $30.00 for a set of six maps and base maps, for plotting purposes, at $6.00 each or $20.00 for a set of six maps. The maps are rolled and shipped postpaid in a tube. □

New Western Regional Geologist for USGS appointed

G. Brent Dalrymple, 44, of Palo Alto, Calif., a research geologist recognized for his work in the field of geochronology, has been appointed Western Regional Geologist for the U.S. Geological Survey (USGS), Department of the Interior, with headquarters in Menlo Park, Calif. He succeeds Joseph I. Ziony, who has returned to special studies on fault hazards of southern California with the Western Center's Office of Earthquake Studies.

Dalrymple, a native Californian and long-term resident of the San Francisco Peninsula, has been working as a geologist at the Western Region headquarters since 1963, when he started his USGS career as a geologist with the Branch of Theoretical Geophysics. He gained early recognition for his published works on the geomagnetic-reversal time scale, one of the key geologic findings that led to the earth science theory of plate tectonics.

Dalrymple has published widely in scientific journals and other publications and has co-authored a textbook on potassium-argon dating. In addition to his early studies on geomagnetic reversals, he has published a series of papers on the hot-spot hypothesis for the origin of the Hawaiian Islands and on such other subjects as the history and timing of volcanoes, the thermoluminescence of lunar samples, and the development of radiometric-dating techniques.

Until his current assignment, Dalrymple had been serving with the Branch of Isotope Geology for some ten years. He first was project chief, then branch representative for the Western Region headquarters. In his post as Western Regional Geologist, he will coordinate all USGS Geologic Division programs and manage division facilities in Alaska, Arizona, California, Hawaii, Idaho, Nevada, Oregon and Washington, as well as the Pacific Trust Territories. □

ABSTRACTS

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

STRATIGRAPHY AND SEDIMENTATION OF THE SPENCER FORMATION IN YAMHILL AND WASHINGTON COUNTIES, OREGON, by Fathi Ayoub Al-Azzaby (M.S., Portland State University, 1980)

The Spencer Formation in Yamhill and Washington, Counties, Oregon, is exposed in a narrow belt 27 km long, from ¼ to 3 km wide, and with a maximum thickness of about 400 m. The formation is composed entirely of sandstone with interbedded thin layers of mudstone in the uppermost member. The sedimentary structure and paleoecology indicate a shallow marine depositional environment. The upper member of the Spencer Formation contains more quartz, plagioclase, and hornblende than does the lower member, but K-feldspar is less abundant than in the lower member. Shallower water conditions for the deposition of the upper member are indicated by sedimentary structures and the abundance of pebbly lenses and coaly material. Eighteen species of megafossils collected from the formation indicate that the Spencer Formation is of the Tejon stage (late Eocene of the West Coast).

The Spencer Formation in the study area is unconformably underlain by fine sediments of the Yamhill Formation of late Eocene (Narizian) age, which are in turn underlain by the upper middle Eocene Tillamook Volcanics. The Spencer Formation is overlain by a unit previously mapped as undifferentiated Oligocene marine sediments (Schlicker and Deacon, 1967). For this thesis, these sediments were separated into three units, partially mapped in the northern part of the study area: (1) A separate mudstone, siltstone, and sandstone unit called in this thesis the Stimson Mill bed, which intertongues with and overlies the Spencer Formation. The stratigraphic position of this unit is uppermost Eocene, not Oligocene as previously interpreted. (2) A thick sequence of interbedded basaltic and carbonaceous fine sandstone, pebbly sandstone, and thin-bedded shale of the Gries Ranch Formation which overlies the Stimson Mill bed of early Oligocene age. (3) A sandstone and mudstone unit, probably the middle Oligocene Pittsburg Bluff Formation, which overlies the Gries Ranch Formation. To the east of the study area, these units are unconformably overlain by the late Oligocene Scappoose Formation, which is, in turn, uncomformably overlain by the Columbia River Basalt Group of Miocene age.

Very well-developed faults with stratigraphic displacement occur throughout the study area, and sills and dikes intrude some of the Eocene and Oligocene rocks.

The considerable thickness of the shallow marine Spencer sandstone unit, along with its good porosity and permeability, well-developed faults, and intertonguing relationship with the overlying unit, suggest that this unit is favorable for the development of good stratigraphic and/or structural oil traps.

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THE PETROGRAPHY, STRUCTURE, AND STRATIGRAPHY OF POWELL BUTTES, CROOK COUNTY, CENTRAL OREGON, by Jan Peter Weidenheim (M.S., Oregon State University, 1980)

Powell Buttes is a major topographic feature located in western Crook County, between Bend and Prineville in central Oregon, and represents a mid-Tertiary silicic volcanic center of probable John Day age. The rocks of Powell Buttes are sparsely porphyritic and include dacite, rhyodacite, basaltic andesite, and flow-banded rhyolite in the form of lava flows and domes.

A warm climate with lush vegetation and frequent ash falls is recorded by carbonized plant remains and ancient soil horizons in tuffaceous sediments. The ash falls were products of Plinean volcanic activity; Pelean-type eruptions produced numerous vitroclastic breccias and lapilli tuffs, some of which contain authigenic clinoptilolite. The deposits and their characteristics suggest that Powell Buttes represents a source area for some John Day air-fall and ash-flow tuffs. The mature topography exhibited by Powell Buttes indicates that erosional processes have been very active there in the past. This implies that Powell Buttes contributed sediment to the nearby Pliocene Deschutes Formation.

Major oxide analyses of Powell Buttes rocks indicate a calc-alkaline suite when plotted on a Peacock diagram and Harker variation diagrams of the major oxides. A plot of Na_2O to K_2O results in an inverse relationship similar to that demonstrated by Walker (1970) for ash-flow tuffs of Oregon, some of which are John Day in age.

A subducting plate has been postulated to have existed approximately 260 km west of the study area during the mid-Tertiary (Atwater, 1970). Calc-alkaline volcanism has been associated with the subduction process and may be related to the silicic lavas exposed at Powell Buttes. Pitts (1979) mapped a major positive gravity anomaly at Powell Buttes and suggested that an olivine-gabbro residuum exists at depth. Other possibilities, however, should be considered because (1) the volume of rhyolite and dacite would require parental mafic and intermediate magmas that should be even more abundant than the silicic lavas, and (2) such residual rocks are not exposed in old, deeply eroded calc-alkaline belts.

A 7.4-km-long east-west normal fault, with the north side downthrown approximately 300 m, is delineated in the central area of Powell Buttes by a subtle, yet abrupt lithologic discontinuity of dacite to rhyolite.

The author has verified the occurrence of geothermal activity in the area adjacent to the northern part of Powell Buttes. Young silicic volcanic centers are usually associated with geothermal activity, but none exist in the region surrounding Powell Buttes.

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Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, no. 12, p. 3513-3536.

Pitts, G. S., 1979, Interpretation of gravity measurements made in the Cascade Mountains and adjoining Basin and Range province in central Oregon: Corvallis, Oreg., Oregon State University master's thesis, 186 p.

Walker, G. W., 1970, Cenozoic ash-flow tuffs of Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 32, no. 6, p. 97-115. □

OIL AND GAS NEWS

Willamette Valley:

American Quasar Petroleum Company's Kenneth Wetgen 26-32, NE¼ sec. 26, T. 13 S., R. 4 W., Linn County, was drilled to a total depth of 2,620 ft and abandoned as a dry hole on August 24, 1981.

Quintana Petroleum Corporation's Gath 1, SE¼ sec. 16, T. 8 S., R. 2 W., Marion County, was also abandoned as a dry hole. The plugging date was September 7, 1981. Total depth was 6,002 ft.

Future Willamette Valley activity includes a proposed 6,000-ft well to be drilled by Reichhold Energy Corporation in Marion County. The location is near Woodburn in sec. 28, T. 5 S., R. 2 W. In addition, American Quasar Petroleum Company will rework the Hickey 9-12 well in Linn County (sec. 9, T. 12 S., R. 2 W.) to increase its production and may also drill an offset well 1 mi to the north.

Clatsop County:

Oregon Natural Gas Development Company (ONGD), a subsidiary of Northwest Natural Gas Company, is one-third owner of a new drilling rig in Oregon. The company, along with Reidel International and Vorhees Drilling, has dubbed the new drilling company ROVOR and has begun drilling Johnson 33-33 in sec. 33, T. 8 N., R. 8 W., Clatsop County. The well is being drilled directionally to the southwest, to a projected depth of 10,000 ft. The new rig will also be used on one or two subsequent wells in Clatsop County for ONGD.

Mist Gas Field:

Reichhold Energy Corporation, operator of all producing wells in the Mist Gas Field, is currently drilling for a new pool discovery in sec. 33, T. 7 N., R. 5 W., 2 mi from the nearest production. After an unsuccessful straight hole to 2,407 ft, the redrill is being directed to the north. □

BLM publishes self-guided tour of Diamond Craters

Diamond Craters, a volcanic complex located about 55 mi southeast of Burns, Harney County, southeastern Oregon, is the subject of an attractive and informational tour guide recently released by the Bureau of Land Management (BLM).

Diamond Craters, which is described in the guide as a "museum of basaltic volcanism," contains a wide variety of volcanic features, including domes, shield volcanoes, lava pits, lava flows, maars, calderas, volcanic bombs, driblet spires, spines, collapse craters, and spatter cones—all in a relatively small area. The guide is designed to make it possible for someone with very little geologic background to find and understand these features.

Written by Ellen M. Benedict, Pacific University, the guide is based on work by numerous geologists including Bruce Nolf, Central Oregon Community College; Robert Bentley, Central Washington University; Norm Peterson, Oregon Department of Geology and Mineral Industries; Edward Groh; George Walker, U.S. Geological Survey; and Pete Mehringer, Washington State University. It is available free of charge from the Bureau of Land Management and may be obtained over the counter from BLM offices at either 729 NE Oregon St., Portland, OR 97208 [phone (503) 231-6273] or 74 S. Alvord St., Burns, OR 97720 [phone (503) 573-2071]. Requests by mail should be sent to the BLM at either Box 2965, Portland, OR 97208 or 74 S. Alvord St., Burns, OR 97720. □

Northwest Mining Association names convention theme and chairman

Howard J. Adams, Inspiration Development Company, has been named chairman of the Northwest Mining Association's 87th annual convention scheduled for December 3-5, 1981, in Spokane, Washington. More than 2,500 mining and industry members from around the world are expected to meet at the Davenport Hotel and Ridpath Motor Inn to listen to papers structured around the convention theme, "Moving Ahead with America."

Adams and Program Chairman Jackie Stephens, U.S. Borax and Chemical Corporation, have scheduled several first-time sessions and papers for the 1981 convention. The Precious Metals session will feature discussions of newly developed precious metals deposits. Desmond Pretorius of South Afria, one of the most renowned international precious metals experts, is scheduled to deliver a paper. Pretorius is also scheduled to address the convention welcoming luncheon on December 3.

Most of the session topics which have proved popular in the past few years, such as geology, metallurgy, foreign developments, student poster, mining, health and safety, will be repeated this year. A drilling short course will precede the convention short course on November 30 to December 2 at the Davenport Hotel.

Registration information for the convention and/or short course is available from the Northwest Mining Association, 633 Peyton Bldg., Spokane, WA 99201, phone (509) 624-1158. □

Guide to USGS information sources available

A guidebook explaining how to obtain a wide range of products and information from the U.S. Geological Survey (USGS) has been revised and is again available free upon request.

The publication shows addresses and phone numbers of more than 30 USGS public service offices, including libraries, Public Inquiries Offices, National Cartographic Information Centers, publication distribution centers, and the Open-File Services Section, all widely-used facilities designed to make USGS earth-science data more readily available to users.

Single copies of the 42-page publication, "A Guide to Obtaining Information from the USGS, 1981," published as U.S. Geological Survey Circular 777, can be obtained free of charge from the U.S. Geological Survey, Text Products Section, Eastern Distribution Branch, 604 South Pickett St., Alexandria, VA 22304. □

GSOC luncheon meetings announced

The Geological Society of the Oregon Country (GSOC) holds noon meetings in the Standard Plaza Building, 1100 SW Sixth Avenue, Portland, in Room A adjacent to the third floor cafeteria. Topics of upcoming meetings and speakers include:

October 16—*The Story of Petrified Wood*, by Albert J. Keen, Amateur Mineralogist.

November 6—*Death Valley, Land of Many Contrasts*, by Esther Kennedy, Naturalist.

November 20—*Oregon Plant and Animal Fossils*, by William N. Orr, Associate Professor, Department of Geology, University of Oregon.

For additional information, contact Viola L. Oberson, Luncheon Chairwoman, phone (503) 282-3685. □

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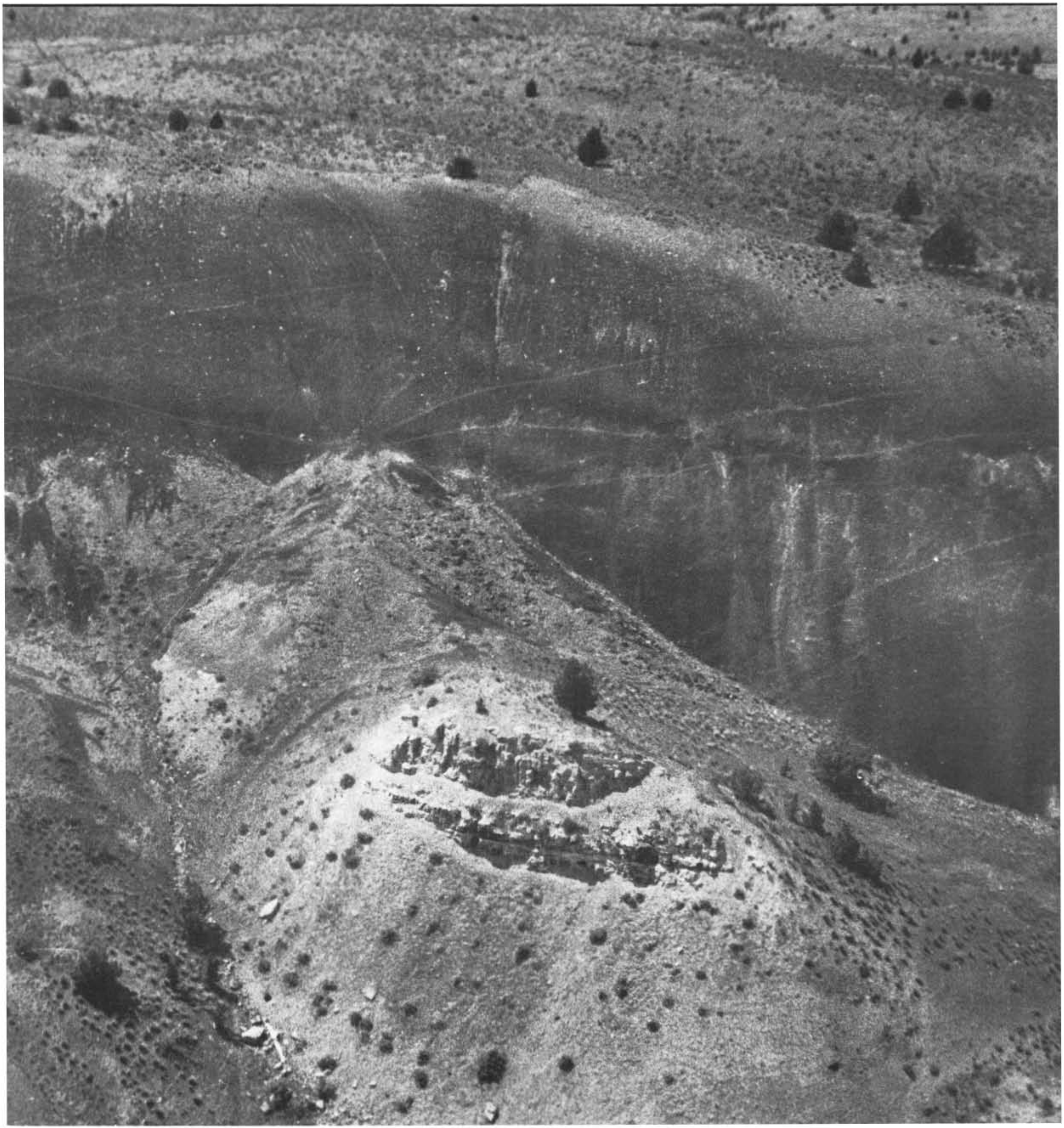

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COVER PHOTO

Oblique aerial view of the Clarno Nut Beds (rocky, light-colored outcrops), middle Eocene stream deposits, overlain by late Eocene and early Oligocene fossil soils of Red Hill (dark slopes), near Clarno, north-central Oregon. Fossil plants and soils from here indicate that vegetation during the Eocene and Oligocene was very different from the scattered sage and juniper of today. See article beginning on next page.

Willamette Valley rock resources, volcanic hazards, and north-central/northeastern Oregon geology subjects of new reports

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the release of three new open-file reports. Open-File Report 0-81-7, *Rock Material Resources of Marion, Polk, Yamhill, and Linn Counties, Oregon*, by Jerry J. Gray and Allan H. Throop, DOGAMI, identifies 1,168 rock material sites with past or present production of sand and gravel, stone, clay, and cinder in the four-county area located in the mid-Willamette Valley. The report summarizes the results of a cooperative study by DOGAMI, the Pacific Northwest Regional Commission, and the Oregon Land Conservation and Development Commission. Included in the 47-page report are tables containing such data as location, status, and size of sites; nature of the resource; mining systems; uses of the product; and reclamation possibilities for the mined-out areas. On three accompanying maps (scale 1:125,000), the sites are located and keyed to the tables of the text. The report is intended to serve as a data base that can be used by planners, politicians, and private citizens in planning and making public decisions concerning land use and in locating resources for road and construction projects. The authors emphasize that the mineral potential of an area should be an integral part of land use considerations. Cost of 0-81-7 is $7.

Open-File Report 0-81-9, *Seismic and Volcanic Hazard Evaluation of the Mount St. Helens Area, Washington, Relative to the Trojan Nuclear Site, Oregon*, by John D. Beaulieu and Norman V. Peterson, DOGAMI, systematically evaluates the relevance of seismic activity and volcanic activity at Mount St. Helens for the nuclear power plant site at Rainier in Columbia County, Oregon. The volcanic hazards investigated include lateral blast, mudflow, ashfall, floods, and pyroclastic flows. The study was funded by the Oregon Department of Energy (ODOE), and this open-file report, which summarizes the results of the study, will be added to the body of technical material maintained by ODOE for guiding the safe operation of the Trojan plant. Purchase price of 0-81-9 is $5.

Open-File Report 0-81-10, *Post-Columbia River Basalt Group Stratigraphy and Map Compilation of the Columbia Plateau, Oregon*, by S.M. Farooqui, R.C. Bunker, R.E. Thoms, and D.C. Clayton of Shannon and Wilson, Inc., Portland, and J.L. Bela, DOGAMI, covers an area of more than 200,000 sq mi in north-central and northeastern Oregon. The report consists of a 79-page text and six blackline maps (scale 1:250,000) covering parts of The Dalles, Pendleton, Grangeville, Baker, Canyon City, and Bend 1° by 2° quadrangles. The maps were compiled from 308 7.5-minute quadrangles which had been mapped by a combination of field reconnaissance and office compilation techniques over a period of two years. Cost of 0-81-10 is $10.

All of these open-file reports are available for inspection or purchase at the Portland office of the Oregon Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. Copies of these reports may also be purchased by mail. Orders under $20 require prepayment. □

CONTENTS

Preliminary observations on fossil soils in the Clarno Formation (Eocene to early Oligocene) near Clarno, Oregon

by Greg Retallack, Department of Geology, University of Oregon, Eugene, Oregon 97403

INTRODUCTION

One would expect fossil soils to be common in sedimentary rocks laid down on dry land. However, since geologists seldom have training in soil science, they often fail to recognize such soils. This is unfortunate because fossil soils can tell us much about the past. They are evidence for the nature of extinct vegetation, depth of ancient water tables and nature of the ground water, rates of subsidence and sedimentation, and ancient topography and climate.

In the summer of 1979, during a brief visit sponsored by the Oregon Museum of Science and Industry (OMSI) Paleontology Research Program, I discovered several fossil soils in the Clarno Formation near Camp Hancock in north-central Oregon (Figure 1). Fossil soils occur in the Clarno Nut Beds, which contain fossil plants and mammals of middle Eocene age; in the overlying red beds of Red Hill; and under a volcanic mudflow which overwhelmed an upright petrified tree (the "Hancock Tree") in Hancock Canyon. The red beds and mudflow are probably, in part, early Oligocene in age, like the rocks of the nearby fossil mammal quarry. The age and relationships of these localities are discussed by Hanson (1973) and Manchester (1979, 1981). All localities are protected from unauthorized collecting by OMSI and the John Day Fossil Beds National Monument.

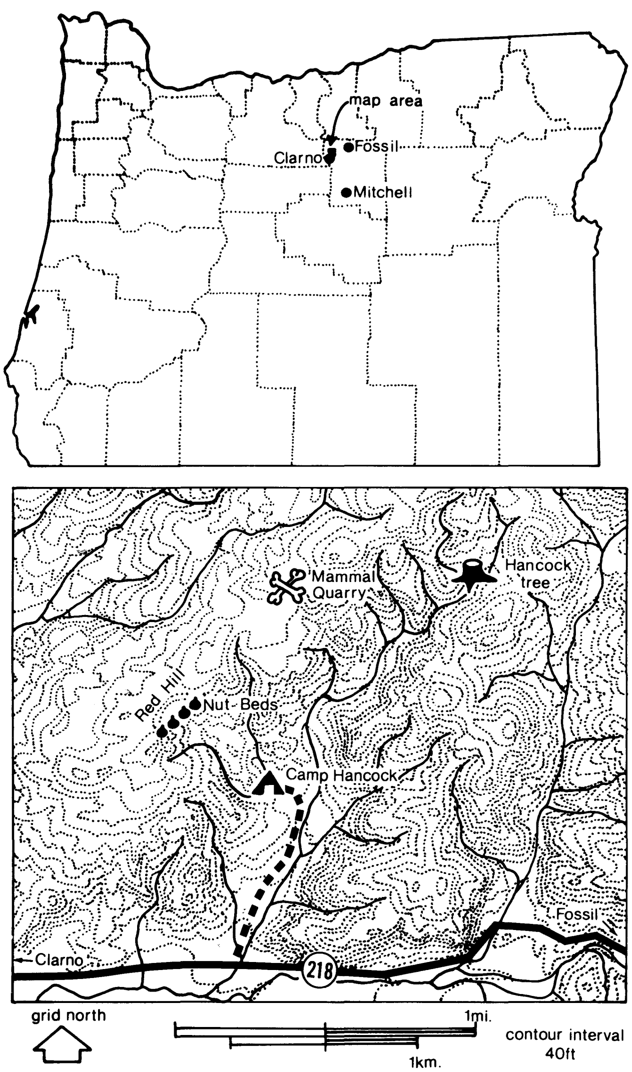

Figure 1. Locality map: Camp Hancock and Clarno fossil soil localities discussed in text.

Thick reddish fossil soils have also been reported by Oles and Enlows (1971) on erosional unconformities below and within the Clarno Formation near Mitchell (Figure 1). Such fossil soils that formed during very long periods of erosion are difficult to interpret, as they may have been initiated under different vegetation and climate than they supported just before burial, and they may also contain relict and residual features of older soils. Only the fossil soils of ancient sedimentary environments near Camp Hancock are considered further here.

AN INTRODUCTION TO MODERN AND FOSSIL SOILS

In terrestrial sedimentary environments such as river valleys, sediment may be moved around by running water, wind, or gravity slides. For most of the time, however, this sediment lies relatively undisturbed. Plants and animals colonize this material after floods. Very soon their activity modifies the sediment at the surface to such an extent that we call this material a soil. It may be penetrated by roots and churned by burrows and may contain decaying leaves and other organic matter. At an early stage of its formation, a new soil may still have some structures formed during the original flooding, such as bedding and ripple marks. Soils with a lot of sedimentary relicts and little change, apart from the addition of organic matter, are called alluvial soils or entisols. With additional time and growth of vegetation, rainfall leachates and other chemicals from plants and soil organisms may leach the upper part of the soil to form an eluvial or A horizon. Eventually, as more material is leached out, the A horizon becomes more enriched with resistant minerals, such as quartz. Not all the material is completely lost from the soil; it may accumulate to form an illuvial or B horizon.

The chemicals involved in these processes may differ in different kinds of soils. In podzolic soils, the A horizon tends to be quartz-rich, sandy, and light colored. It is leached of clay, humus, iron, and aluminum. These accumulate in the B horizon, which thus tends to be more massive, clayey, dark, and red.

Soils do not persist indefinitely. Eventually they are either covered by sediment or eroded away. In subsiding river valleys, of the sort in which many thick sequences of terrestrial sedimentary rocks accumulate, soils are periodically covered by flood sediment. If the flood is especially powerful and up to 1 m (3 ft) of alluvium is deposited over the soil, smashing down vegetation and driving off the animals, then a new soil will

Figure 2. Clarno Nut Beds, light-colored near-stream deposits, and overlying clayey fossil soils of Red Hill. OMSI Paleontology Research team (arrow, lower left) is excavating at base of large down-slumped block of Nut Beds. Colorful variegated badlands like Red Hill commonly contain numerous fossil soils.

begin to form at a higher level.

If this later soil never develops deeply enough to obscure the underlying soil, then geologists will have no trouble distinguishing the older fossil soil from the younger one. However, such simple sequences are seldom found. If only a few inches of sediment are deposited in a flooded forest, for example, trees will continue to grow and incorporate the new sediment into the existing soil. In this way, a sequence that is comprised mainly of A horizons may accumulate, a situation here called an accreting soil. Another complication is that the B horizon of a later soil may form in the A horizon of an earlier one. In this case, the younger B horizon may have a variety of older soil features (pedorelicts) inherited from the older A horizon. Such situations can be very difficult for geologists to interpret.

Another difficulty with studying older fossil soils is that they change during many years of burial and compaction. Such post-depositional changes that are not severe enough to be regarded as metamorphism are commonly called diagenesis. For example, soils may have considerable accumulations (up to 3.6 percent) of plant silica bodies (phytoliths) in the A horizon. During diagenesis, this silica can be dissolved and reprecipitated to form a hard flinty cement (Retallack, 1977). As another example, well-drained soils may have oxides of ferric iron in the form of gels or minerals such as limonite and goethite, which form a light-brown or yellow stain. During diagenesis, these iron oxides may change to the brick-red mineral hematite, giving the fossil soil a much redder color (Walker, 1974).

FOSSIL SOILS OF THE CLARNO FORMATION

There are at least three kinds of fossil soil in the Clarno Formation at Camp Hancock. As in the modern world, each of these probably formed under different vegetation and in different parts of the landscape. Although they are not necessarily all of exactly the same age, they give an idea of the mosaic of terrestrial environments during the Eocene and early Oligocene in the area which is now Camp Hancock.

Alluvial fossil soils of the Nut Beds

The Nut Beds consist of conglomerates and sandstones, both probably deposited by streams (Figure 2). The sandstone beds are usually less than 0.3 m (1 ft) thick and alternate with silty layers. Many of these sandstones are riddled with fossil horsetail plants (*Equisetum*) in life position (Figure 3). Some of the disturbed upper portions of the sandstones may be small rills or weathered hoof prints of Eocene ungulate mammals. These sediments are very similar to those found in modern streamside levees. The sandstones were probably weakly differentiated alluvial soils covered in thickets of *Equisetum.*

Figure 3. Equisetum *in position of growth in lower Nut Beds. Arrow points to branching axis. Stems are approximately a third of an inch in diameter. (Photo courtesy of S.R. Manchester)*

Horsetails are well known for their abundant phytoliths. Living mature plants average 10 percent silica by dry weight. This is why they make such excellent pot cleaners and once were called scouring rushes. Although silica-charged waters from nearby volcanic hot springs may have been important in the silicification of the Nut Beds, substantial contributions of silica from these accumulator plants are also likely.

Bottomland forested soils of Red Hill

The origin of red beds, variegated beds, and badlands has long been somewhat of a mystery. Undoubtedly they originated in several different ways, but many are turning out to be accumulations of fossil soils. My own excavations of the slumped and weathered exposures of Red Hill, just above the Nut Beds, revealed a number of fossil soils. Some of these were difficult to interpret and were evidently accreting soils. In these, each additional increment of flood sediment appeared to have been incorporated into pre-existing soil without destroying the vegetation, so that successive soil horizons were overlapping.

Some of the fossil soils in Red Hill, however, were well preserved (Figure 4). These appear to have been well-differentiated soils with gray A horizons and reddish-brown B horizons. Large drab tubules, the reduced clay around individual large roots, extend down from the A into the B horizon. These ancient soils were evidently vegetated by large trees, probably a kind of rain forest similar to that which provided much of the plant debris to the Nut Beds. Many of the plant remains in the Nut Beds have living relatives in subtropical broadleaf forests. The diversity of the plant remains and the numerous vines indicate that it was a rain forest or jungle (Manchester, 1981), at least along the streams in which the plants are preserved. Carbonaceous and gray layers, patches of purple-colored claystone, and the pattern of mottling of the well-differentiated, reddish clayey fossil soils are indications of moist, partly waterlogged conditions. The former water table was probably within 1 m (3 ft) of the surface. Thus, these fossil soils were valley bottom soils. This fact and plant remains preserved in the Nut Beds indicate that Eocene valley bottoms near Camp Hancock were vegetated by rain forest.

Each fossil soil in Red Hill represents a depositional hiatus of at least several hundred, perhaps several million, years. There are many superimposed paleosols in Red Hill. Thus, it is likely that the unconformity thought to separate older and younger parts of the Clarno Formation is split into a number of minor unconformities in Red Hill.

Upland forested soils of Hancock Canyon

One of the silicified stumps and logs in the volcanic mudflow in Hancock Canyon is still standing upright (Figure 5), rooted in a fossil soil that is not as well differentiated as the soils on Red Hill. Although better differentiated than the horsetail-bearing fossil soils of the Nut Beds, the Hancock Canyon soil is still best regarded as an alluvial soil. It has a silicified, leached, root-penetrated A horizon and also a well-preserved leaf litter. Only the flatter leaves of the lower leaf litter have been preserved in place. The curled loose leaves have been swept up into the overriding mudflow and form fossiliferous lenses as much as a foot above the base of the flow. Beyond a very indistinct clay-rich layer, the fossil soil does not have a well-differentiated B horizon. There is also much relict bedding in the fossil soil. These features are probably due to a relatively short time of formation, probably little longer than it took to grow the preserved crop of tree trunks. They could also have developed because the area was more elevated and seldom had a waterlogged layer near the surface, in which case chemicals and clay leached out of the A horizon would wash right out of the profile rather than accumulate there. The volcanic mudflow presumably slid down the flanks of a nearby volcano and is additional evidence that these soils formed in higher parts of the landscape. Interestingly, the fossil flora associated with these fossil soils is quite different from that at the Nut Beds. There are fewer species of wood and leaves, mainly forms similar to katsura (*Cercidiphyllum*) and sycamore (*Platanus*; Manchester, personal communication, 1980). Modern relatives of these plants are trees of cool temperate climates. Perhaps this less diverse, cold-adapted flora forested hills adjacent to the humid rain-forested bottomlands near Camp Hancock during the Eocene and early Oligocene.

Eocene fossil soils similar to those in Hancock Canyon are also found in northeastern Yellowstone National Park, where there are many horizons of silicified stumps in a great pile of volcanic mudflows, erupted rocks, and stream and lake deposits (Dorf, 1964; Fritz, 1980). On Specimen Ridge, some of these fossil soils have well-differentiated silicified A horizons as well as massive, clay-rich B horizons (Retallack, 1981). None have reddish B horizons of bottomland fossil soils, like those of Red Hill. The Yellowstone fossil soils were largely forested by conifers of cool, temperate climatic affinities, such as pine (*Pinus*) and redwood (*Sequoia*). As in this region today, it is likely that conifers grew at higher elevations than angiosperms.

Figure 4. Well-differentiated fossil soil in the middle of east slope of Red Hill, with light-gray A horizon over reddish B horizon. Hammer gives scale.

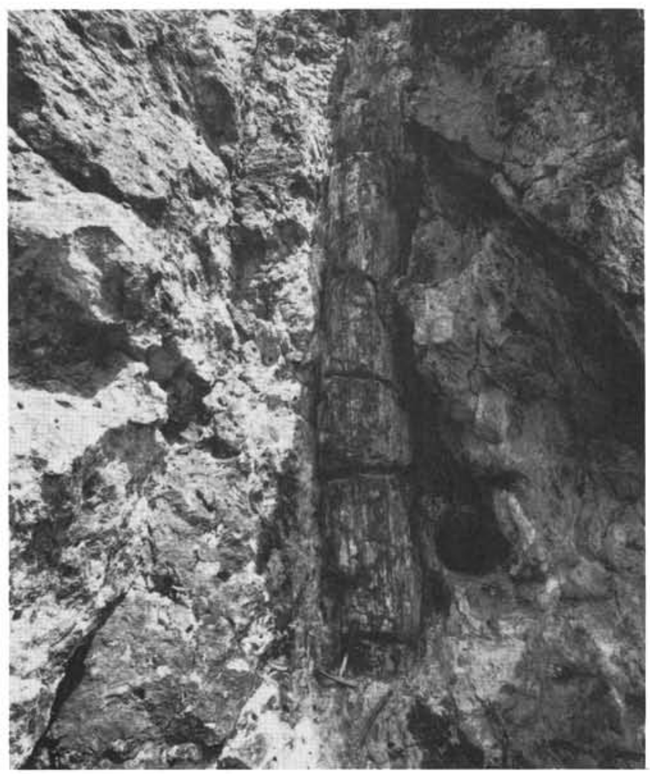

*Figure 5. "Hancock Tree," most similar to modern katsura (*Cercidiphyllum*; S.R. Manchester, personal communication, 1980), preserved in position of growth by a thick volcanic mudflow. Hammer gives scale.*

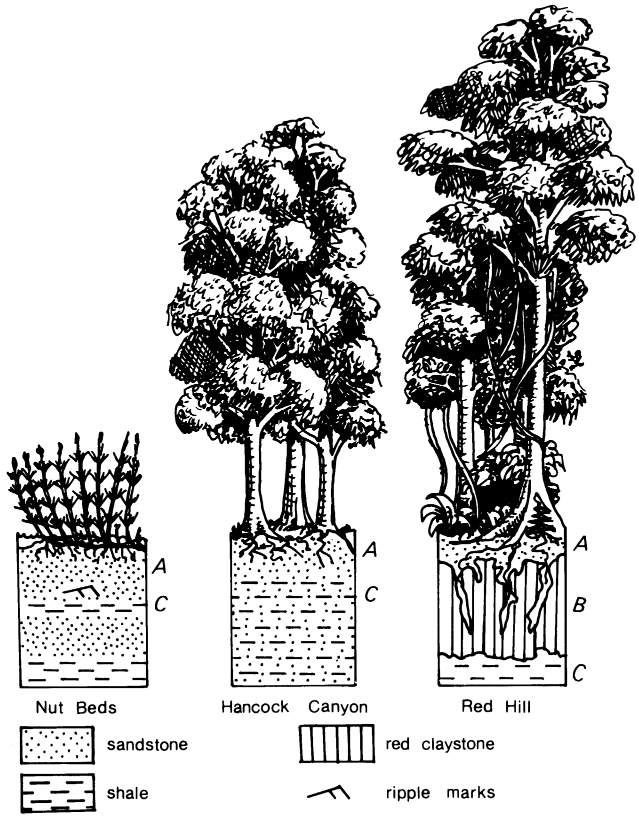

Figure 6. Soil horizons and reconstructed vegetation of some fossil soils of the Clarno Formation (schematic).

CONCLUSION

Fossil soils near Camp Hancock are important evidence of Eocene and early Oligocene vegetation and landscapes. They are reconstructed in Figure 6. Even in areas where the geology is well known, fossil studies can add much to our understanding of ancient terrestrial ecosystems. Although abundant in nonmarine rocks of all ages, pre-Quaternary fossil soils remain comparatively little studied. We need to know more about them.

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Annual award for exemplary mined land reclamation to be given

Realizing that it is as desirable to recognize outstanding performance as it is to punish offenders, the Governing Board of the Oregon Department of Geology and Mineral Industries at its April 9, 1981, meeting approved a proposal to recognize and honor an outstanding example of mined land reclamation each year. One Oregon site demonstrating either voluntary or mandatory reclamation of mined land will be selected each year. The first award will be announced in June 1982.

These awards are intended to reward outstanding achievement by operators and to further the goal of reclamation by awarding trophies and providing appropriate publicity.

Some of the criteria that will be considered include the following: The future value of the site; the imagination, innovativeness, and effectiveness involved in the completed planned reclamation; safety characteristics; aesthetics; and the appropriateness to local environment.

Nominations for consideration will be welcomed from any source. Most nominations are expected to come from personnel who frequently observe sites, such as the Mined Land Reclamation (MLR) staff of the Oregon Department of Geology and Mineral Industries; their counterparts in the Bureau of Land Management, the U.S. Forest Service, and other departments of the State; county personnel; environmental groups; and industry. Nominations will be screened by the MLR professionals, and the final selection will be by a committee which will include a member from an environmental organization, a member from industry, and the supervisor of the Mined Land Reclamation Program.

A permanent trophy listing the names of the winners will be displayed in the office of the State Geologist. An individual plaque will also be given permanently to each annual winner. An illustrated article of recognition will be published in *Oregon Geology*, and news of the award will be given to the appropriate trade journals. Whenever possible, a field day or tour of the site will be arranged with the winner's approval and will be open to the public.

The annual announcement and award are anticipated to be made on the nearest practical date to the 15th of June each year.

—Paul F. Lawson, Supervisor
Mined Land Reclamation Program

State legislation affecting mineral industry summarized

The 61st Oregon Legislative Assembly completed its biennial session on August 2, 1981. Several bills of particular interest to the mineral industry in Oregon were passed, including various changes in the regulation of surface mining, oil and gas drilling, and geothermal energy drilling and production.

SURFACE MINING

HB 2160—The Oregon surface mined land reclamation law (Oregon Revised Statutes 517) underwent significant change. The maximum amount of bonding for certain new large-scale "nonaggregate" mines including coal, uranium, and metal mines was increased from $500 per acre to $10,000 per acre. The actual amount of reclamation bonds for these operations will continue to be based on the estimated cost of reclamation consistent with the approved reclamation plan for each mine.

The ceiling for penalties and liens was also increased to $10,000 per acre to be consistent with the higher bonding limits.

The increased bonding, penalty, and lien limits do not apply to sand and gravel pits, rock quarries, or underground mines. Small placer gold mines moving less than 5,000 cubic yards per year are exempted from the higher bonding level.

This legislation also revises the definition of surface mining in Oregon by increasing the minimum amount of material extracted from 2,500 to 5,000 cubic yards in a 12-month period. Thus surface mines in general may not be required to comply with various provisions of the reclamation law if they remove no more than 5,000 cubic yards in any 12-month period.

HB 2220—The operating permit fee required of surface mine operators was increased to $390 per year for a new site and $290 for annual renewal of an existing site.

OIL AND GAS DRILLING

HB 2146—House Bill 2146 provides several administrative changes to the Oregon oil and gas conservation law (ORS 522) and streamlines the existing law with respect to drilling of wells. The bill provides for issuance of drilling permits without formal hearing for wells located outside of established spacing unit areas if topographic or geologic conditions justify such approval.

This legislation also requires the reclamation of drill sites and filling of sumps for other subsequent beneficial uses such as grazing or timber management.

The new law allows the State Geologist to extend the two-year confidentiality period for information from oil and gas wells.

GEOTHERMAL ENERGY

SB 116—Senate Bill 116 provides a comprehensive procedure for unitization of ownership interests in geothermal energy reservoirs. A two-stage approach involves voluntary agreement by the private parties initially or later compulsory unitization by the Governing Board of the Department of Geology and Mineral Industries in cases where the voluntary agreement is not possible. A suitable majority of both royalty and operating interests must approve any unitization plan, and it would take into consideration pre-existing plant dedicated area agreements.

SB 117—Senate Bill 117 clarifies the respective responsibilities of the Department of Geology and Mineral Industries and Department of Water Resources in the regulation of geothermal energy production. A coordination mechanism is provided to deal with possible conflicts between geothermal energy and ground-water development. Fluid production less than 250°F from wells will be regulated by the Department of Water Resources, and hotter fluids will be treated as a geothermal resource.

HB 2147—A simplified regulatory procedure for geothermal well drilling is provided by House Bill 2147, which revises ORS 522. A requirement in the existing law to obtain a production bond after drilling a successful well has been deleted. A time limit of 180 days to begin well drilling after receiving a permit has been added, with provision for extension up to a total of 360 days. The hearing requirements for certain actions of the Governing Board have been streamlined.

CONCLUSION

The new legislation described above clarifies the state's regulatory process and should encourage responsible development and production of the important mineral and energy commodities. □

Northwest Mining Association offers drilling course

Explorationists and operators can gain a practical knowledge of drilling in the classroom at the Northwest Mining Association short course to be held November 30-December 2, 1981, at the Davenport Hotel in Spokane, Washington.

"In the past, the art of drilling could only be learned on the job," said Short Course Director William J. Whinnen. The course, Drilling and Management of Drilling Projects, is geared toward the geologist or engineer in charge of a field or mine project. It will cover techniques, systems, equipment, and costs. "The NWMA drilling course differs from other courses for drillers in that it includes a comprehensive study of the management of drilling projects," Whinnen said.

Working papers will be available to class participants. A formal volume based on the course will be published next year and mailed to those who attend the drilling course.

The short course will precede the Northwest Mining Association 87th annual convention which is scheduled for December 3-5 in Spokane. Registration information for the drilling course and/or convention is available from the Northwest Mining Association, 633 Peyton Bldg., Spokane, WA 99201; phone (509) 624-1158. □

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Please note that the cover page of this issue bears a REMINDER TO RENEW, if your subscription expires in December. Most subscriptions expire in that month, so make sure yours is not lost in the shuffle and RENEW NOW! And—while you're at it—why not consider *Oregon Geology* as a Christmas gift subscription? □

On the marketing of earth science information: A review of USGS Circular 813

Earth scientists may not have had to face such moral dilemmas as the possible misuse of knowledge about the atom or about genetic engineering, but for most geologists, the day of searching for knowledge just for its own sake without attention to its practical application is long past. In fact, increasing energy, environmental, and land use pressures today require more and more attention to such applications of the earth scientist's knowledge. What is most pressing now is the subsequent problem: the task of transferring earth science information to those in our society who need it—citizens, business, industry, and local governments involved in decisions about land and resource problems.

This is the context for a recent U.S. Geological Survey publication (Circular 813, 1979) by Thomas F. Bates, entitled *Transferring Earth Science Information to Decisionmakers*. In it, Bates describes and analyzes the experiences of the USGS in its attempts to bridge the gap between the "producers" of the earth science information, the scientists, and the "users" of that information, the citizens and their administrative, planning, and regulating decisionmakers. A representative sample of projects from five major programs administered by the USGS Land Information and Analysis Office (LIA) is discussed on the basis of evaluation reports and many interviews with people personally involved in earth science information exchange.

Even a brief glance at the two groups of producers and consumers shows that the main burden of getting information across lies on the shoulders of the earth scientists. They are a fairly well defined and consistent group facing, on the other side of the "interface," a wide spectrum of users, a "user community" that also changes continuously, e.g., in citizen participation and interest, in elected officials and staff members. And, according to Bates' assessment of the present situation, "the earth science community as a whole has yet to realize that it has primary responsibility for ensuring adequate and proper use of earth science information by the public and its representatives" (p. 2). Geologists, too, have to "sell their stuff"—which may not always be as easy as in the recent wave of public interest in volcanology and Mount St. Helens—and they have to see that it gets to the right people.

Bates' paper addresses the following questions:

- Who are the new users of earth science information, and what characteristics and interests place them in a position to relate more closely to the earth science community?
- What are the needs of these users for earth science information?
- What specific forces generate pressure for increased application of earth science information to land use planning problems?
- What are some of the difficulties faced by the earth science producer and the user communities in working together on these needs and problems?
- What are some of the more successful methods, as demonstrated on USGS projects, of transferring earth science information to nontechnical users?

Some of the points to keep in mind, if not direct answers to specific problems, that have emerged from the USGS experience include:

- The need for the earth scientist to adjust the language and format of the information to the users' degree of familiarity with the issue.
- The advisability of an alliance with an intermediary type of organization, where effective identification and involvement of key representatives from user communities is difficult.
- The fact that "product demand must often be created by a variety of educational efforts," not only to show that information is available but also that it will indeed be helpful.

One of the five major programs was the three-year Pacific Northwest Land Resource Inventory Demonstration (PNLRID) project. Its purpose was to determine the technical and economic feasibility of using Landsat data as an aid in the solution of regional land resource problems in Idaho, Oregon, and Washington. The program received effective intermediary support from a task force of the Pacific Northwest Regional Commission. Throughout the 3-year project, Federal agency personnel at the EROS Data Center and NASA's Ames Research Center worked with some 125 representatives of the State and local government user agencies to familiarize them with the possibilities of using remote sensing in land resource management areas, such as forestry, natural resources, agriculture, water resources, fish and wildlife, and urban change.

In conclusion, Bates calls for a mobilization of the entire earth science community, to achieve what LIA has attempted to do with its projects:

- Create nationwide awareness of earth science information needs and uses.
- Provide specialized, technical information in a form and language understandable to the intelligent citizen.
- Engage in the educational, advisory, and review services necessary to assist the public and its representatives in making effective use of that information.

The methods and approaches will differ, Bates concludes, but "all will require establishing intimate working relations by every possible means of communication and interaction between the two 'communities' involved—the earth scientists and the land resource planners and decisionmakers throughout the Nation."

Circular 813 can be obtained at no charge from a number of U.S. Geological Survey offices; the nearest of them is the USGS Public Inquiries Office, U.S. Courthouse, Room 678, West 920 Riverside Avenue, Spokane, Washington 99201, phone (509) 456-2524.

—Klaus Neuendorf, Editor/Librarian
Oregon Department of Geology and
Mineral Industries

November AIME meeting to be held in Corvallis

The Oregon section of the American Institute of Mining, Metallurgical, and Petroleum Engineers will meet Friday, November 20, in Corvallis. Neal Wagner will be the speaker for the evening; his topic will be "Hewlett-Packard, Corvallis—Products, Technology, and Analytical Applications." The exact location of the meeting has not yet been selected, but AIME members should receive notices of the meeting in the mail. Social hour is at 6 p.m., dinner at 7 p.m., and talk at 8 p.m. For reservations or more information, contact Mike York, Accident and Failure Investigations, Inc., 2107 NW Fillmore, Corvallis, OR 97330; phone (503) 757-0349. The public is invited. □

OIL AND GAS NEWS

Willamette Valley:

Exploration in the Willamette Valley continues to result in dry holes during recent months. American Quasar, however, was encouraged enough by shows of gas to run a production string and do some testing on a recent well near Jefferson. The well, Wolverton 13-31, in sec. 13, T. 10 S., R. 3 W., Marion County, was finally abandoned on October 7, at a total depth of 4,555 ft.

Using the same Paul Graham rig that drilled the Wolverton well, American Quasar moved back onto Hickey 9-12, the company's producing gas well in Linn County. On line since May of this year, the well has been disappointing, so additional perforating was done during this workover job. Results were poor, however, and the well was abandoned on October 15.

Clatsop County:

Drilling continues on Oregon Natural Gas Development Company's Johnson 33-33, southeast of Astoria. Barring trouble with the hole, the proposed total depth of 10,000 ft should be reached during November. There have been signs of H_2S in the hole but no reported shows of oil or gas.

Mist Gas Field:

A redrill of Reichhold Energy's Longview Fibre 12-33 has resulted in one of the Mist Gas Field's best producers. We reported last month that the straight hole was dry; since then, however, a redrill to a depth of 2,475 ft has resulted in a tested potential of nearly 5 million cu ft per day of gas. The well, located in sec. 33, T. 7 N., R. 5 W., followed a dry hole in the same quarter section. Production will be from a new pool in the upper Clark and Wilson sand, the same productive sand as elsewhere in the field. Construction of a gathering line has begun, and an offset well, Longview Fibre 41-32, was spudded on October 9 in the adjacent sec. 32.

Applications for leasing State lands:

The Division of State Lands will hold another lease sale after the first of the year, as soon as applications for 100,000 acres have been received. So far, the Salem office has received applications for over 85,000 acres. Counties receiving the most interest include Malheur (55,000 acres), Harney (10,000 acres), Lake (10,000 acres), Marion and Clackamas (4,000 acres), and Clatsop (2,500 acres). Terms of State leases are $1 per acre per year and a ⅛ royalty on leases with a 10-year term.

BLM oil and gas lease application fee increase:

The fee for filing an oil and gas lease application with the Bureau of Land Management (BLM) increased from $10 to $25 beginning October 1, 1981. Roger Dierking of BLM's records and data management branch said that the fee is charged when the BLM receives offers for land that has previously not been leased or for lands where leases have expired or have been canceled. BLM is the agency responsible for oil and gas leasing on federal lands.

Applications submitted on or after October 1 that are not accompanied by the $25 filing fee will not be accepted by BLM. The fees are used to defray the government's cost of processing the applications, Dierking said. The increase was directed by the Omnibus Budget Reconciliation Act of 1981.

Under the federal government's oil and gas leasing program, the government issues a lease to the first offerer on a noncompetitive basis for those lands that are not known to be an area of productive oil and gas deposits. When more than one person files for lands that have previously been leased, a drawing is held to determine the lessee.

The fee has not changed since 1949. BLM estimates that the increase in filing fees will bring in about $80 million annually, nationwide.

In Oregon, there are 1,198 oil and gas leases in effect on federal land, covering 2.1 million acres. In Washington, 126 leases have been issued for 148,517 acres. In addition, applications are pending for several million acres more. □

Test of Oregon's hottest geothermal well confirms a substantial resource

The U.S. Geological Survey's geothermal test hole in Newberry Crater, Deschutes County, Oregon, has been tested and abandoned. The hole, reported in the September 1981 *Oregon Geology,* was cored to a depth of 3,057 ft. A temperature of 509°F was encountered at 3,051 ft. Substantial gas and steam encountered in the last 6 ft of the well halted the drilling.

A 20-hour flow test found 12,000 gallons per day of fluid condensed from their separator and 1,000,000 cu ft per day of gas phase, including steam and other volatiles. The temperature of the fluid in the separator was 295°F. Initial calculated bottom-hole pressure was 900 psi. These temperatures and flow rates may be adequate for electrical generation, subject to further testing.

When testing was completed, the drill rods were stuck in the hole, and the hole was plugged with cement. No plans for further drilling in the area have been announced. □

Bear attack victim honored as outstanding handicapped federal employee

Cynthia Dusel-Bacon, 35, of Menlo Park, California, a geologist with the U.S. Geological Survey (USGS) and victim of a bear attack, was honored as one of the ten outstanding handicapped federal employees of the year at ceremonies on October 8, 1981, in Washington, D.C. The ceremonies were part of the celebration of the International Year of Disabled Persons and National Employ the Handicapped Week.

While on a routine geologic field assignment in a remote area of east-central Alaska in 1977, Cynthia Dusel-Bacon was attacked by a small black bear. Although badly injured during the hour-long attack, she never lost consciousness and was able to eventually reach her walkie-talkie and call for help. Her left arm was so badly damaged that it was immediately amputated above the elbow. Despite attempts to save her right arm, it was amputated at the shoulder about 10 days later.

She waged a long hard battle to find alternative ways to duplicate functions that had been lost with her arms. Today she is back at work in Menlo Park, Calif., as a project chief in the Branch of Alaskan Geology, working on topical studies of metamorphic rocks in east central Alaska, in addition to compiling a map providing information about metamorphic rocks in all of Alaska. She has just recently completed her second field trip to Alaska since the ill-fated attack.

Besides her work for USGS, she is active in speaking to civic groups about her rehabilitation and views as a disabled person and in making herself available to help other amputees. She remains physically active by swimming, hiking, birdwatching, riding a tandem bicycle with her husband Charlie, a fellow USGS geologist, and, in general, being self-sufficient. □

ABSTRACT

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

SEDIMENTATION, STRATIGRAPHY, AND FACIES VARIATION OF THE LOWER TO MIDDLE MIOCENE ASTORIA FORMATION IN OREGON, by David Michael Cooper (Ph.D., Oregon State University, 1981)

The lower to middle Miocene Astoria Formation consists of four distinct lithologic members which crop out in three separate embayments along the Oregon coast. These units are the Newport sandstone and Big Creek sandstone, new members which are herein described and informally named, and the Angora Peak sandstone and Silver Point mudstone members.

The Angora Peak member is composed of up to 1,000 ft of fine- to coarse-grained, micaceous, feldspathic, and volcanic sandstone. Sedimentological and faunal evidence suggest that the bulk of this sandstone was deposited in a high energy, wave-dominated shallow marine environment. Conglomerate channels, coal beds, finely laminated carbonaceous siltstone, and a complex intertonguing of the marine/nonmarine parts of the member indicate a fluvial-deltaic origin. This delta consisted of shifting distributary channels and interdistributary deposits fronted by an extensive system of beaches and bars similar to modern high-energy wave-dominated deltas. A fence diagram of the facies suggests that a prograding delta extended from the Angora Peak-Hug Point area southward to Cape Meares during early Astoria time, followed by continued subsidence and concurrent marine transgression. At Astoria, most of the formation is composed of deep-marine mudstone, indicating that a deep-marine basin existed there throughout most of Astoria time.

Overlying gradationally and intertonguing with the Angora Peak member is the 700-ft-thick Silver Point member. This member consists of well-laminated to structureless, micaceous and carbonaceous silty mudstone with numerous well-bedded graded turbidite sandstones in the lower part of the member. The member was deposited in low energy, open to semi-restricted marine conditions of neritic to upper bathyal depths, possibly in a prodeltaic environment. Evidence in the unit for minor local littoral conditions also exists. Oversteepening of the prograding deltaic wedge resulted in slumping of the delta front sands to form turbidity flows which transported the coarse clastics into the deeper water prodelta environment.

The Newport sandstone member is composed of 1,000 ft of moderately to well-sorted, medium- to fine-grained sandstone. These sheet sands were deposited probably as subtidal bar and continental shelf sands distributed by longshore currents on the southern flanks of the Angora Peak delta. This member fines upward, becoming well laminated and resembling the Silver Point mudstones, to which it is tentatively correlated.

East of Astoria, the 1,400-ft-thick Big Creek sandstone member is the lateral equivalent of the Angora Peak and Silver Point members. The Big Creek sandstones coarsen, then fine upward, indicating an influx of coarser sands, probably by a northward shift in the discharge from the Angora Peak delta. Deposition was in intertidal to middle neritic marine conditions on the continental shelf. The upper part of the Big Creek sandstone intertongues to the west with upper bathyal marine mudstones. These sandstone tongues formed as a result of gravity-induced fluidized sediment flows transporting shallow-marine sands into the deeper marine environment.

All of the members are lithologically similar, although the strata in the Newport embayment may have been, in part, semi-isolated from those to the north. Sediment sources were dominantly calc-alkaline and arkosic rocks, probably andesites, dacites, and pyroclastics of the ancestral Cascades, from local Coast Range Eocene basaltic highs as well as from minor recycling of sedimentary units. Petrography and chemistry indicate that some of the Astoria sediments were derived from eastern Oregon and Washington, Idaho, Montana, and British Columbia via an ancestral Columbia River drainage system. Paleocurrent dispersal patterns support this hypothesis.

Micro-textures of sand grains viewed with the scanning electron microscope indicate deposition in high-energy fluvial-marine conditions, adding further evidence of the depositional environment interpreted from other data.

Facies patterns indicate that petroleum potential is greatest in the Angora Peak delta sheet and inner shelf sandstones in the near-offshore continental shelf between Cannon Beach and Cape Kiwanda. □

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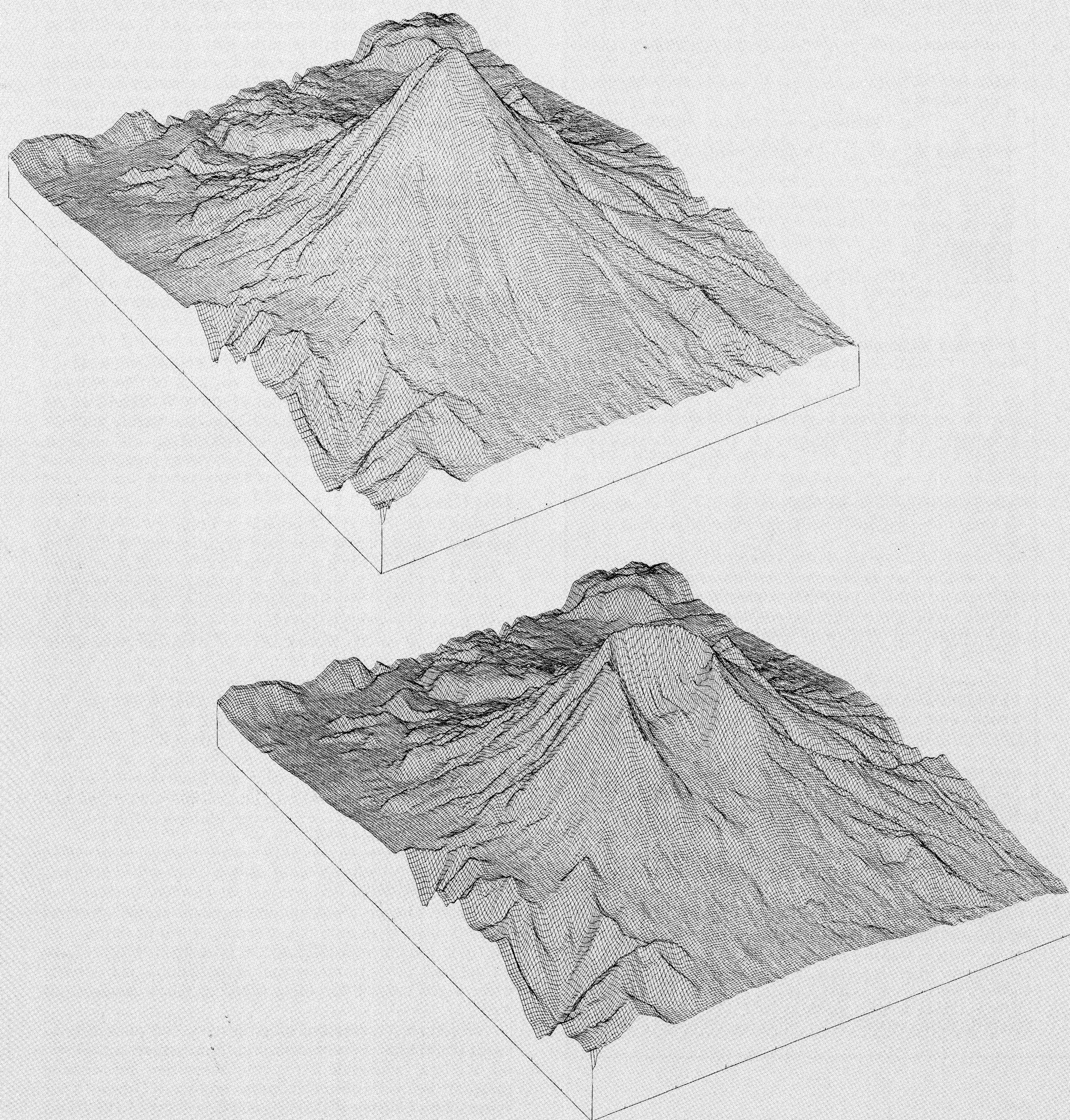

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COVER PHOTO

Pre- and post-eruption digital elevation models of Mount St. Helens, Washington, produced at the U.S. Geological Survey Western Mapping Center. View is from northeast of the volcano, which is located 35 miles east of the Trojan nuclear power plant at Rainier, Oregon. The article beginning on the next page discusses the seismic and volcanic hazards of Mount St. Helens relative to the Trojan nuclear power plant.

OIL AND GAS NEWS

Willamette Valley:

American Quasar Petroleum Company, one of Oregon's most active independent operators, discovered Oregon's second gas field near Lebanon by drilling Hickey 9-12 in March of this year. Subsequent completion of the well resulted in a cumulative production of about 10.4 million cubic feet from May to September 1981. However, steady decline in pressure and volume resulted in the abandonment of the well last month, after Quasar tried perforating additional intervals.

Not easily discouraged, American Quasar has filed an application to drill Weber Farms 12-22 in sec. 12, T. 13 S., R. 3 W., Linn County. The proposed depth is 5,000 ft, and drilling will commence after the first of the year.

Other Willamette Valley activity includes Reichhold Energy Corporation's Bagdanoff 23-28. Located in sec. 28, T. 5 S., R. 2 W., Marion County, the well is nearing its proposed total depth of 6,000 ft, after mechanical problems with the rig were solved.

Douglas County:

One and a half years after Northwest Exploration Company's drilling effort in Douglas County, Florida Exploration Company of Houston plans a well there. To be located in sec. 4, T. 21 S., R. 6 W., Florida Exploration Company 1-4 is proposed for a depth of 10,000 ft. This well, to be drilled in 1982, will be followed by at least one more in the county.

Clatsop County:

Oregon Natural Gas Development Company continues to drill Johnson 33-33 in sec. 33, T. 8 N., R. 8 W. The well has nearly reached its proposed depth of 10,000 ft. Results of the drilling will not be known until logging and testing are performed. When finished here, the ROVOR rig will move to Yakima, Washington, to drill for Shell Oil Company.

Mist Gas Field:

Reichhold Energy Corporation's Longview Fibre 12-33 was completed as a new pool discovery on September 27. The well in sec. 33, T. 7 N., R. 5 W., extended the productive limits of the field 2 mi to the northwest and tested at over 4.5 million cubic feet per day. The productive well was a redrill to 2,475 ft, following a straight dry hole to 2,407 ft. In sec. 32, Reichhold has already drilled an offset well, Longview Fibre 41-32, which turned out to be dry at a total depth of 2,487 ft.

Other activity in Mist includes Hansen 44-15 in sec. 15, T. 6 N., R. 5 W., drilled by Reichhold. Drilled in October, the well was abandoned at a total depth of 2,782 ft.

Reichhold's deep test, Columbia County 32-10, in sec. 10, T. 6 N., R. 5 W., was suspended after reaching 7,807 ft. The well, drilled to look for a deep sand, was cased with 8⅝-in casing through the known producing interval and will be used as a gas storage and withdrawal well when the pool is converted to storage, probably next year. □

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Seismic and volcanic hazard evaluation of the Mount St. Helens area relative to the Trojan nuclear site: Highlights of a recent study*

by John D. Beaulieu, Deputy State Geologist, and
Norman V. Peterson, Geologist, Oregon Department of Geology and Mineral Industries

INTRODUCTION

The Trojan nuclear power plant, Rainier, Oregon, is situated 35 mi (56 km) west of Mount St. Helens (Figure 1). The cataclysmic May 18, 1980, eruption of this Washington Cascade volcano has renewed interest in volcanic hazard potential as a siting consideration. Additionally, ongoing study of seismic activity in the area has suggested the presence of a 60-mi (100-km)-long seismic zone representing a possible fault or faults passing within approximately 30 mi (50 km) of the plant site.

On the basis of these considerations, the Oregon Department of Energy (ODOE) requested the Oregon Department of Geology and Mineral Industries (DOGAMI) on May 18, 1981, to conduct an investigation of the volcanic hazards and earthquake potential of Mount St. Helens as they relate to the Trojan facility. The resulting study* is a systematic and comprehensive inquiry into existing assumptions, data, and conclusions which bear directly or indirectly on the formulation of a credible response to the ODOE request. In order to obtain as objective results as possible in view of finite limits of observation, data were critically checked and subjected to multiple analytical techniques, conclusions were cross-checked, and multiple interpretations of critical features were given where possible. Where only limited data were available, they were reviewed more conservatively, by choosing the greatest reasonable hazard among possible alternatives as the basis for conclusions.

In the interpretation of seismic potential, the presumed fault was analyzed by using six source-parameter equations, an approximation of seismic moment, and a consideration of recurrence frequency as suggested by limited historic records. The resulting estimate of maximum possible earthquake was interpreted in terms of existing attenuation models to yield a seismic response spectrum at the site. This, then, was compared with the ground motion data used in the original design of the Trojan facility.

Volcanic hazards, including lateral blast, ash fall, pyroclastic flow, mudflow, and floods, were analyzed. The magnitude of the maximum credible event for each volcanic hazard was determined on the basis of the geologic and historic record at and surrounding Mount St. Helens, an understanding of analogous volcanoes and the mechanics of the processes in question, and a judgment of the adequacy of available data.

Space does not allow full development, in this article, of all of the concepts presented in the study, nor does it allow a complete listing of references used. For further information, the reader is referred to the original report (Beaulieu and Peterson, 1981).

REGIONAL GEOLOGIC SETTING

General

Current plate tectonic theory holds that the North American Plate is drifting westward relative to the East Pacific Plate and has actually overridden it along a zone of subduction (Atwater, 1970). This theory is based on a wide variety of scientific data involving both onshore and offshore areas. Recent syntheses are proceeding toward coherent explanations of the deformations observed in space and time throughout the western North American Plate. Appeal to this theory was judged prudent for full analysis of the specific activity addressed by the present study.

Plate tectonic models understandably contain a range of uncertainty yet are of general benefit in view of common agreement on major points. In particular, attempts at developing a regional synthesis of plate tectonic geologic processes are of value in interpreting specific geologic events or features. They place rational constraints on speculation on one hand while guiding rational extrapolations on the other.

Plate tectonic boundaries in the northwestern United States

The major plate tectonic boundaries between the North American Plate and the East Pacific Plate include the Queen Charlotte-Fairweather Fault along the west coast of Canada and the San Andreas Fault of California (Figure 2). Both are simple faults of the transform type and exhibit ongoing right-lateral displacement. Vector calculations of gross plate movements suggest rates of displacement of 2-2.5 in (5-6 cm) per year (Silver, 1971; Coney, 1978), whereas geodetic measurements and regional geologic mapping indicate displacements of slightly more than half that amount (Smith, 1977; Coney, 1978).

In the Pacific Northwest between Vancouver Island and Cape Mendocino, several small spreading centers off the coast separate the Queen Charlotte-Fairweather Fault and the San Andreas Fault and yield several small plates collectively referred to here as the Farallon (Juan de Fuca) Plate. From south to north are located the eastern end of the Mendocino (Gorda) Escarpment, Gorda Ridge, Blanco Fracture Zone, Juan de Fuca Ridge, Sovanco Fracture Zone, Explorer Ridge, and the Queen Charlotte-Fairweather Fault system.

Carlson (1976), Davis (1977), Riddihough and Hyndman (1977), and Silver (1978), among others, agree that although there is apparently no inclined Benioff (seismic) zone beneath western Washington and Oregon, the Farallon Plate is probably being subducted to the east beneath North America. Furthermore, Crosson (1980) presents seismic focal data that strongly suggest a shallow, east-dipping Benioff zone beneath the western and central parts of the Puget Trough at the latitude of the Olympic Peninsula.

Other features suggesting Quaternary subduction beneath the continent include the compressive deformation of late

* The study, *Seismic and Volcanic Hazard Evaluation of the Mount St. Helens area, Washington, Relative to the Trojan Nuclear Site, Oregon*, was released by the Oregon Department of Geology and Mineral Industries as Open-File Report 0-81-9 (see p. 146 of the November issue of *Oregon Geology*).

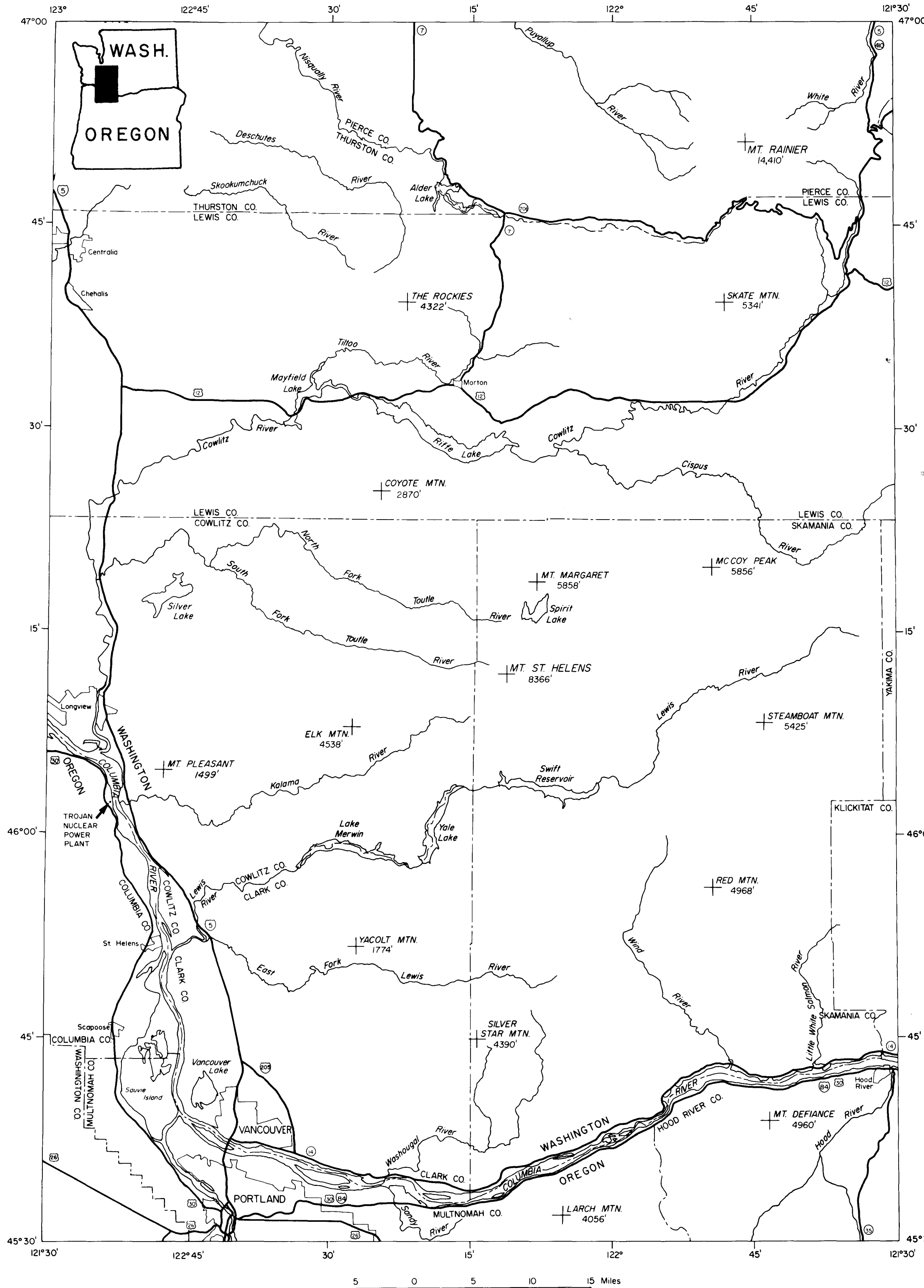

Figure 1. Location map of Mount St. Helens area.

Pleistocene sediments along the base of the Oregon-Washington continental slope and the nature of the deep (36-42 mi [60-70 km]) Puget Sound-Gulf Islands earthquakes discussed below. Further, heat-flow measurements define a belt of low heat flow inland from the coast changing to high heat flow near the volcanic arc (Cascade Range). Gravity anomalies over the margin display the linear "high and low" pattern characteristic of active plate margins. Continued volcanism in the Cascades, although of a lower rate than sometimes in the past, also suggests continuing subduction.

The general lack of historic seismicity along the subduction zone is anomalous but can be attributed to a variety of features particular to the Farallon (Juan de Fuca) Plate. These include (1) its relative thinness, which may not allow large-scale accumulation of stress, (2) its relative youth and its thick insulating cover of sediments, both of which may result in maintenance of higher temperatures and higher plasticity, and (3) a relatively low rate of subduction which may favor aseismic (rather than seismic) creep.

The relative direction of convergence between the North American and Farallon (Juan de Fuca) Plates is unclear. Estimates are based on the movement vectors of various plates as shown by the insert in Figure 2. There the vectors are plotted relative to north with information derived from pertinent geologic features so that P_N is the movement of the Pacific Plate relative to the North American Plate (using the San Andreas Fault as a reference), F_P is the movement of the Farallon Plate relative to the Pacific Plate (using the Juan de Fuca Ridge as a reference), and N_F is the movement of the North American Plate relative to the Farallon Plate (defined by connecting the other two vectors). Rates of movement are 2.4 in (6.0 cm) per year for P_N and 2.3 in (5.8 cm) per year for F_P. N_F here is indicative of underthrusting at an angle of N. 38° E. at a rate of 1.2 in (3 cm) per year oblique to the subduction zone. The obliqueness of the subduction may impose a right-lateral component of strain on the overriding North American Plate (Davis, 1981).

The specific angle of convergence, such as the one considered in this study, may be significant in understanding major structures in the North American Plate. In addition to the above example of oblique subduction (N. 38° E.), a suggested angle of N. 50° E. is proposed by Riddihough (1977). Neither angle is totally consistent with the postulated orientation (N. 20° W.) of the Mount St. Helens seismic zone of Weaver and Smith (1981). This inconsistency may be resolved in the future with (1) more precise vectoral solutions, (2) refined definition of the Mount St. Helens seismic zone and its orientation, (3) integration of knowledge of possible deep crustal pre-existing zones of weakness, or (4) better understanding of the overall geology of the study area.

Tentative conclusions can be drawn about the specific geometry of the subducting plate. Seismic activity at depths greater than 12 mi (20 km) indicates east-west tension (Hill, 1978). The 1965 Seattle earthquake was produced along a north-south-striking normal fault at a depth of 36 mi (60 km). The faulting is attributed by Davis (1977) to tension on the upper part of the subducting plate in a region of abrupt steepening to the east. The depth of the 1965 Seattle quake suggests a 10°-15° dip of the subducting plate eastward from the base of the continental slope to the Puget Sound area. Farther to the east, a 30°-50° dip is required to provide for the generation of magma for Quaternary Cascade volcanoes east of the Puget Trough. For the 1965 Seattle earthquake (longitude 122°20′ W.), Langston and Blum (1977) interpret an east-dipping (70°) low-velocity zone at a depth of 25-34 mi (41-56 km), a conclusion in general agreement with the subduction model.

Oblique subduction as described above allows for a variety of models of deformation in the northwestern United States. Conceivably, northeast subduction of the lower plate (oblique to the margin of the upper plate) and northwesterly shear of the upper plate can accommodate the regional stress regime. The relative significance of the two mechanisms should reflect the degree of "locking" of the two plates. A locked situation would be seen in dominant northwest shear and inelastic permanent deformation of the upper plate, whereas an unlocked situation would be seen in dominant seismic or aseismic creep along the subduction zone. Further, mechanical response to the oblique subduction may vary from time to time and from place to place.

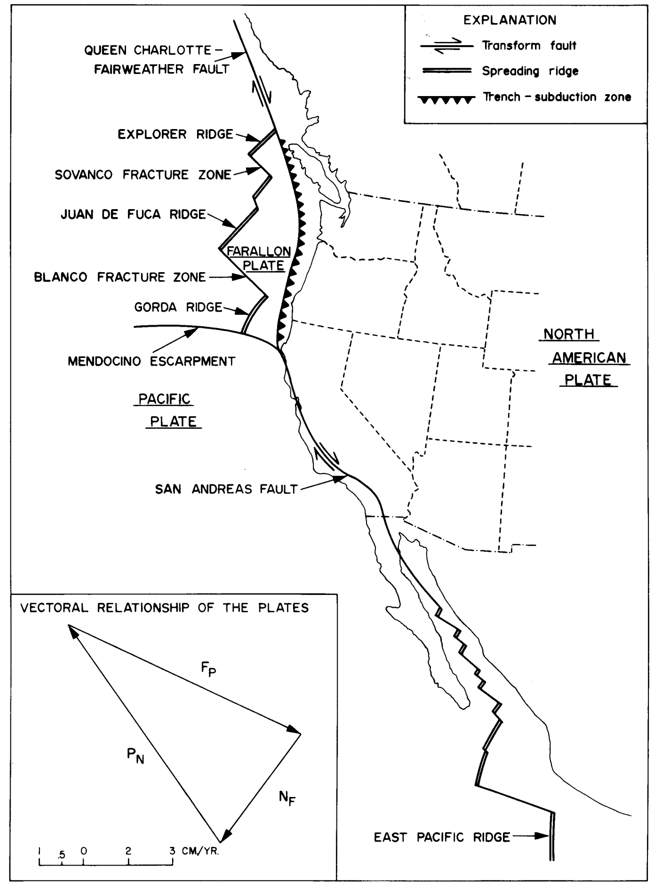

Figure 2. Plate tectonic setting of Oregon and Washington.

The only major earthquakes which appear to be associated with the subduction zone occur beneath Puget Sound and Vancouver Island. There, the subducted plate appears to be under east-west tension—at least in the upper parts. Decoupling of the plates in the zone of seismicity west of the Cascades can be postulated. Additional decoupling through aseismic means is possible elsewhere, including regions beneath the Cascades. However, northwest shear along the Mount St. Helens seismic zone can be construed as evidence for a partially locked situation at present. From a geologic or seismologic standpoint, it is not possible to provide a complete and final statement of the degree of locking or unlocking of the plates at this time.

In an analogous area of oblique subduction near New Zealand, plate locking and unlocking in a historic time frame are documented by Walcott (1978), who notes that final interpretations in complex areas of that type must consider seismic and aseismic subduction, lateral faulting in the upper plate, and permanent inelastic deformation of the upper plate.

The Mount St. Helens seismic zone

The Mount St. Helens seismic zone is defined by Weaver and Smith (1981) generally as a N. 20° W.-trending band of seismic activity in the State of Washington. It extends a maximum distance of 60 mi (100 km) from Swift Reservoir south of Mount St. Helens, past Mount St. Helens, and on to the vicinity of Alder Lake on the Nisqually River to the north. It is defined by Weaver and Smith (1981) on the basis of earthquakes of magnitude $M_c \geqslant 2.8$ (see section on earthquake magnitude) occurring between mid-1970 and February 15, 1981, at depths of 12 mi (20 km) or less. Right-lateral fault-plane solutions with vertical faults are available for some of the events.

Detailed evaluation of post-May 18, 1980, seismic events suggests that the zone to the south of Mount St. Helens involves an additional fault rather than an extension of a single fault (Weaver and others, 1981). Crosson (1972), using a broader data base with lower resolution in terms of locations, describes the seismicity of western Washington as diffuse rather than as occurring in well-defined zones.

Conceptually, the Mount St. Helens seismic zone lies above the locus of relative steepening of the underlying plate that is subducting to the east. Also, in a regional kinematic model, the seismic zone is favorably situated to accommodate right-lateral shear over an obliquely subducting plate. The seismic zone is bounded on the north by the Puget Sound province and possibly to the south by the subprovince of the Cascade Range characterized by relatively voluminous outpourings of basaltic to dacitic lava in an east-west extensional regime. Available gravity data (Gower, 1978) do not suggest continuation of the zone northward beneath the Puget Sound area. Thus, regional geologic considerations bound the length of the feature.

Available geologic maps are of reconnaissance type and do not depict faulting of the type suggested by the seismic data as defined here. Yet the extent and shallow depth of the seismic activity suggest the presence of one or more faults at the surface. Synoptic rational lineament maps (Barrash and others, 1981) prepared for this study were not checked in the field but do provide indirect indications of possible faults. A synoptic rational lineament map is a map of lineaments from relatively small-scale (large-area) satellite, U-2, and side-looking airborne radar (SLAR) imagery in which the kinds of lineaments to be plotted are objectively defined in advance. As northerly-trending lineaments do not lend themselves to easy detection with the east-west SLAR flight strips used in this study, the absence of northerly-trending lineaments was interpreted conservatively.

The regional geologic considerations discussed above suggest that a long, north-northwest-trending fault, if it does exist, probably will lie in an area of complex deformation arising from oblique subduction. Given the ambiguous results of the lineament analysis, it follows that a conservative mode of analysis must consider the possibility of a long, single fault.

In conclusion, the Mount St. Helens seismic zone is a zone of shallow seismic activity of right-lateral type for which geologic faults are not mapped but for which strike-slip faulting can be rationalized in terms of plate tectonic theory and available lineament data. The zone, therefore, may include (1) a regional single fault at depth; (2) several lesser colinear, parallel, or en echelon faults in a zone; or (3) volumes of rock undergoing diffuse inelastic strain in addition to more local faulting. Although evidence for a single regional fault is not compelling, such a model is adopted here because it is not conclusively eliminated by existing data and is the most conservative interpretation.

SEISMIC EVALUATION OF MOUNT ST. HELENS SEISMIC ZONE RELATIVE TO THE TROJAN SITE

Earthquake magnitude

Earthquake magnitude is a measure of earthquake energy based on records (seismograms) recorded on seismometers. Magnitude values are indicated with decimal numbers on a logarithmic scale. The Richter magnitude (M) familiar to earthquake reports is precisely defined by Richter as the "logarithm (to base 10) of the maximum seismic-wave amplitude (in thousandths of a millimeter) recorded on a special seismograph called the Wood-Anderson, at a distance of 100 km from the earthquake epicenter." Other common measures of magnitude in present use merely reflect measurements derived from different parts of the "wave train."

The most common measures of earthquake magnitude include M_s (surface waves), M_l (local body waves), and M_b (body waves). In recent years, another measure of magnitude, Coda magnitude (M_c), has been adopted in the Puget Sound area by Crosson (1972, 1974). With this system, magnitude is derived from the duration of the earthquake seismogram between defined limits. The magnitude (M_c) that is so defined is analogous to Richter magnitude (M) of traditional usage.

For quakes larger than $M_s \cong 8.3 \pm 0.3$, additional energy released by the quake occurs in wave lengths too great to be measured by equipment in common usage. For these, the M_s scale is said to be saturated. Here the concept of seismic moment (M_o) is particularly helpful (for $M_s \cong 8.3 \pm 0.3$, $M_o \geqslant 10^{28}$ dyne-cm). Kanamori and Anderson (1975) relate M_o to M_s for values of M_s up to 8.0-8.5. It is important to note that for values of $M_o \geqslant 10^{28}$ there are no corresponding values of M_s except by extrapolation. Therefore, correlating acceleration to M_s for these large quakes is not possible from an empiric standpoint.

Fault interpretation

The maximum possible earthquake for a given fault can be estimated by using the length of maximum possible surface rupture or by determining the seismic moment which is then correlated with magnitude. In addition, development of a recurrence frequency curve for the structure allows a determination of how often the maximum possible quake may occur or a judgment of whether or not such a quake will occur.

As part of this study, the maximum possible surface rupture of the Mount St. Helens seismic zone was determined, using six available equations. Seismic moment (M_o) was also determined by using the best available data for pressure drop and surface area of rupture. In a conservative approach, it was assumed that the Mount St. Helens seismic zone represents a single contiguous fault, although it is more probable that it represents several faults of lesser size and earthquake potential.

For the Mount St. Helens seismic shear zone, the most conservative approach is to assume that the total zone represents a single fault (60 mi [100 km]) and that the fault is active along 50 percent of its length (30 mi [50 km]) in a maximum possible quake event. Available rupture-length equations yield a maximum possible quake of $M = 6.0\text{-}7.4$. Assuming the zone represents more than one fault or activity along 25 percent (15 mi [25 km]) of the total length of a single fault (60 mi [100 km]), a maximum possible quake of $M = 5.7\text{-}7.1$ is indicated. A preliminary analysis using the concept of seismic moment yielded a maximum possible magnitude of $M, M_o = 7.2$.

A preliminary curve for the Mount St. Helens seismic zone (Figure 3) shows that a quake of $M, M_o = 7.2$ will occur

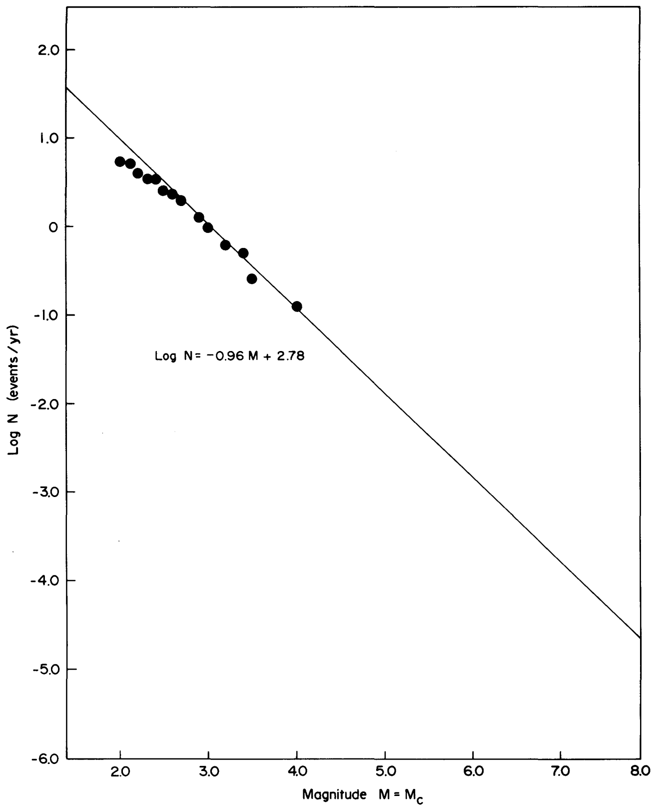

Figure 3. Generalized recurrence frequency curve for the Mount St. Helens seismic zone.

statistically approximately once every 10,000 years. If the Mount St. Helens seismic zone represents a single fault (60 mi [100 km]) and if the fault ruptures along one-half of its length (30 mi [50 km]) to yield a maximum possible quake, then such a quake will probably occur about once every 10,000 years. The short time span of observation of data is noted, and large extrapolations may not be appropriate.

If it is assumed that maximum possible quakes for a region occur once every few hundred years consistent with the data of Sykes (1965), then the maximum possible quake for the Mount St. Helens seismic zone is clearly less, being on the order of M = 5.2 for a 100-year recurrence frequency or M = 6.2 for a 1,000-year recurrence frequency.

As a matter of geologic judgment, it would seem unreasonable that stress would accumulate for a period of 10,000 years prior to release in the largest possible quake in the fault zone. It is more likely that stress will be relieved in other ways over shorter time frames. Time frames of a few hundreds of years are more realistic worldwide (Sykes, 1965). Thus, the preliminary frequency curve indicates that the largest possible quake conservatively determined from source parameters and seismic moment ($M, M_o = 7.2$) is probably too large in view of the historic record.

Ground motion at the Trojan site

The effect of a given earthquake at a given site is dependent upon the specific characteristics of the earthquake, fault, site, and transmission of seismic waves from the fault to the site. For this study, acceleration, ground velocity, and displacement were determined in a conservative manner using available relationships with magnitude $M, M_o = 7.2$ and distance of 30 mi (50 km) from the Mount St. Helens seismic zone to the Trojan site. For each, the more conservative or realistic figure was selected when more than one figure was available. The data were then plotted on the response spectrum of the Final Safety Assessment Report (FSAR) for the safe shutdown earthquake for the Trojan nuclear power plant (Portland General Electric Company, 1976). This provided a comparison with the original design considerations of the facility. Relationships were also presented for approximating earthquake duration and predominant period.

The relationship of ground acceleration at a site to earthquake magnitude and to distance from the epicenter is presented graphically by Housner (1965), Cloud and Perez (1971), Seed and Idriss (1970), Schnabel and Seed (1973), and Boore and others (1978). Although their graphs are based in part on different sets of data from different areas, they display a general consistency for sites more than a few miles from an epicenter. Boore and others (1978) distinguish between rock sites and soil sites. Joyner and others (1981) develop an equation for deriving acceleration from magnitude and distance.

Assuming a maximum possible earthquake of magnitude $M, M_o = 7.2$ at a distance of 30 mi (50 km), the following acceleration values are derived from the various graphs: Housner (1965), 0.27 *g*; Cloud and Perez (1971), 0.25 *g*; Seed and Idriss (1970), 0.15 *g*; Schnabel and Seed (1973), 0.17 *g*; Boore and others (1978), 0.15 *g*; and Joyner and others (1981), 0.17 *g*.

The more recent models are derived from more comprehensive and refined data sets. They give greater consideration of ground conditions and are based on more thorough statistical analysis. Consequently, for the Trojan site, a maximum possible acceleration of 0.17 *g* was selected.

Conclusions

1. The Mount St. Helens seismic zone of Weaver and Smith (1981), a N. 20° W.-trending zone of moderate seismic activity extending about 60 mi (100 km) through the Western Cascades of Washington, consists of one or more presumed faults. Conservative analysis using a variety of available equations including the concept of seismic moment indicates a maximum possible earthquake of $M, M_o = 7.2$. Consideration of limited historic data suggests that a lesser quake of possible M = 6.2 is a more reasonable maximum possible earthquake.

2. Assuming an $M, M_o = 7.2$ quake to be in the realm of possibility for the purpose of nuclear power plant siting, the following figures are derived for ground motion at the Trojan site: maximum horizontal acceleration = 0.17 *g*; maximum horizontal velocity = 10 in (25 cm) per s; and maximum horizontal displacement = 4 in (10 cm). The Trojan facility is designed to withstand this magnitude of ground motion with no appreciable damage. Limited historic data suggest a very low probability (10^{-4} per year) for such an earthquake in the Mount St. Helens seismic zone.

VOLCANIC EVALUATION OF MOUNT ST. HELENS RELATIVE TO THE TROJAN SITE

Introduction

Mount St. Helens is a relatively young volcanic cone in the Cascade Range of Washington. The general geology of the volcano is characterized by dacite domes, pyroclastic flows, lahars, mudflows, and tephra, with the last 4,500 years of its eruptive history well documented by Crandell and Mullineaux (1978) and the earlier 35,000 years documented in more general form by Crandell and Mullineaux (1973), Hyde (1975), and others. Minor flows of basalt and andesite within the past few thousand years have also been noted.

The procedure used in this study was aimed at placing bounds on the maximum credible volcanic events at Mount St. Helens that might impact Trojan. A maximum credible event is the greatest event of a given type that could reasonably be expected to occur, given the geologic history and stage of development of the volcano. This approach is the same that was used in the analysis of earthquakes in the sense that conclusions were based on current knowledge of the actual geologic feature in question.

Volcanic hazards evaluated in this survey include ash fall, pyroclastic flows, mudflows, floods, and lateral blasts. The evaluations were based on existing published and unpublished data and were designed to identify the maximum credible event for each type of hazard under investigation. Andesitic and basaltic lava flows are present on the flanks of the volcano; however, the nonexplosive nature of the volcanic activity associated with their eruption and the short distance they extend from the volcano (maximum 9 mi [15 km]) excludes them from consideration as a volcanic hazard in this investigation.

Lateral blast

Lateral blast (violent nuée ardente) is the forceful, directed release of volcanic material laterally from the sides of a volcano. These blasts are usually accompanied by pyroclastic flows. In some cases, the violence of the eruption is the result of gas pressure that has built up under an obstacle; in other cases, it may be caused by the rapid generation of a body of volatiles and gas too immense to be accommodated by an open, pre-existing vent. The effects of lateral blasts, by their nature, are not fully preserved in the geologic record and therefore are difficult to interpret in terms of maximum credible events for a given vent.

Although a lateral blast may be associated with an ash eruption, the violence of a given lateral blast does not necessarily correlate with the volume of the ash. Further, lateral blasts at Mount St. Helens appear in a general way to be more closely related to dome formation. Examining the last 1,500 years of activity of the volcano, Crandell and Mullineaux (1978) record that a lateral blast approximately 1,000 years B.P. scattered rock debris a distance of 4 mi (6 km) northeastward from Sugar Bowl, a dome located 1,000 ft (300 m) lower than the Goat Rocks dome on the northwest side of the volcano. The blast was associated with the emerging dome and little ash and was minor in comparison with the lateral blast of May 18, 1980, which was itself associated with the summit and Goat Rocks domes. In both the Sugar Bowl and summit and Goat Rocks events, the most recent active dome was the site of the blast. Geologic maps of Mount St. Helens (Hopson, 1980; Kienle, 1980) as it was before the May 18, 1980, eruption show that there were domes located at the summit and on all sides except the south. Pyroclastic flow deposits are also present in most of the drainages surrounding the volcano. Large explosive eruptions could take place at the site of any of these domes sometime in the life of the volcano, although this is not likely in the present eruptive cycle.

A review of the literature on eruptions of the lateral-blast type, including the May 18, 1980, Mount St. Helens eruption, suggests that such eruptions generally occur early in an eruptive cycle. In general terms, the lateral blast of May 18, 1980, was caused by a sudden unroofing of volatile-rich magma within the vent. This was preceded by magmatic activity, an earthquake, and a catastrophic landslide. Although the landslide was the immediate trigger, it is clear that the driving mechanism was the broader eruptive activity which began in late March of 1980 or earlier. The lateral blast of May 18 resulted in complete devastation for distances of up to 12 mi (20 km) and sear zones up to 15 mi (25 km) from Mount St. Helens.

The lateral blast of May 18, 1980, probably was an event unexcelled in the history of the volcano. However, even if the blast had been directed toward Trojan 35 mi (56 km) distant, it would have had no impact on that facility because it affected areas a maximum of 15 mi (25 km) away. Furthermore, the direction from Mount St. Helens to Trojan (S. 72° W.) relative to the present configuration of the cone effectively precludes lateral blast as a serious consideration to the Trojan site.

Ash fall

Ash fall is the accumulation of airborne, fine-grained volcanic debris ejected in a volcanic eruption. Because of their wide distribution over a variety of landforms, ash falls are well preserved in the geologic record. The geologic record can then provide a reliable measure of maximum credible events for a volcano, if the geologic record is adequately defined.

Detailed studies of Mount St. Helens prior to the eruption of May 18, 1980 (Hyde, 1975; Mullineaux, Hyde, and Rubin, 1975; Crandell and Mullineaux, 1978; Hoblitt and others, 1980) provide us with fairly complete knowledge of the eruptive history of the volcano and allow a reasonable and accurate assessment of the maximum credible ash fall.

In the past 4,500 years, large ash falls have been restricted to the north, east, and south sides of the volcano. From field measurements, Crandell and Mullineaux (1975, 1978) and Mullineaux, Hyde, and Rubin (1975) have recognized at least five periods of ash fall activity and designate them as ash fall layers or sets of layers (Table 1).

Table 1. *Large Mount St. Helens ash falls in the last 4,500 years**

Layer or set	Thickness of ash on Mount St. Helens	Time of eruption in radiocarbon years B.P.
T	1.5 ft (50 cm)	150-200
W	5 ft (150 cm)	450
B	1 ft (30 cm)	1,500-2,000
P	2.5 ft (70 cm)	2,500-3,000
Y	3-6 ft (100-200 cm)	3,000-4,000

* Table adapted from Mullineaux, Hyde, and Rubin (1975) and Crandell and Mullineaux (1978).

Hoblitt and others (1980) describe in more detail tephra (ash) set W as being erupted during a period of volcanic activity designated as the Kalama period (about 450 years B.P.) and the tephra set T erupted during a later period of volcanic activity called the Goat Rocks period (about 180 years B.P.). They also describe a minor ash eruption with measurable ash deposits as occurring in 1842 A.D. (only 139 years B.P.).

We know of no reported occurrence of volcanic ash of Mount St. Helens origin in the geologic record in the vicinity of the Trojan site. Small accumulations of a few millimeters thickness, such as those of the present eruptive cycle, may escape detection in the geologic record.

From measurements of individual layers in the sets, Crandell and Mullineaux (1978) estimate the Yn event to be the largest ash eruption in the 40,000-year history of the volcano. This ash eruption, which was probably several cubic kilometers in volume, sent a relatively narrow plume of ash to the north-northeast. Along the axis of maximum deposition, Crandell and Mullineaux measured 2 ft (60 cm) thickness at a distance of 30 mi (50 km). By comparison, the May 18, 1980, event deposited 1.8 in (4.5 cm) of ash at a rate of 0.52 in (1.3

cm) per hour at Packwood, Washington, along the axis of maximum deposition and equidistant from Mount St. Helens as Trojan. The tephra was blown rapidly to the northeast across Washington and Idaho in a relatively narrow plume and reached western Montana in less than 11 hours. The ash layer generally thinned with distance from the volcano and the axis of the lobe.

Large events occurring before 4,500 years B.P. are noted by Hyde (1975) and include an event (35,000-40,000 years B.P.) which may be present in the silt of the Willamette Valley (C.G. Newhall, 1981, personal communication). At the type section of the Willamette Silt (mid-Willamette Valley), Glenn (1965) notes a 0.5-in (1.3-cm)-thick layer of ash that is approximately at the appropriate stratigraphic position.

The thickness measurements of Crandell and Mullineaux (1978) have allowed them to estimate the volumes of ash falls over a wide range of eruption sizes. They list (1) 0.01 km^3 volume for an eruption in 1842 (unnamed layer); (2) 0.1 km^3 for an eruption of 150-200 years B.P. (layer T); and (3) 1 km^3 for the largest eruption (about 4,000 years B.P.) (layer Yn). Kienle (1980), in a review of the Mount St. Helens geologic record, calculates equivalent magma volumes for some of the ash fall deposits and estimates layer T as 0.4 km^3 and layer Yn as 2.4 km^3. In addition, he calculates an equivalent magma volume for layer Wn of 1.7 km^3. Using isomass calculations, which are probably more conservative and more accurate than some of the techniques employed above, Sarna-Wojcicki (1980) calculates a magma mass equivalent of 0.14 km^3 for the May 18, 1980, ash eruption. Kienle estimates a volume of 0.20 km^3.

Assuming the Yn event to be the maximum credible event that can be expected from the volcano, it can be shown that a maximum credible event along the axis of maximum accumulation is 24 in (60 cm) of ash at a distance of 30 mi (50 km) from the vent. There has been one such eruption in the past 4,500 years, and it is doubtful that any events of similar magnitude have occurred in the rest of the life of the volcano.

Maximum credible ash fall at Trojan from Mount St. Helens is a function of volume of ash erupted and direction of transport. An additional consideration during the present eruptive cycle is the limitation that the existing open conduit may place on the occurrence of a large eruption. The existence of an active eruptive cycle limits the chance of a large eruption in the short term, in the sense that an open vent is now available to release volatiles. It does not, however, rule out the possibility of a large eruption entirely. Some prior eruptions (Kalama, 340-450 years B.P., and Goat Rocks, 1800 A.D.) follow dacite-andesite-dacite patterns and demonstrate a measure of disorder and lack of predictability in the large-scale sequence of behavior of the volcano. Thus, from a conservative standpoint, the timing between events may also exhibit disorder. We can therefore place limits on the size of maximum credible events, but in an absolute sense we cannot do so with the timing. The existence of an active vent may reduce the chances of a maximum credible event by a factor of 10 to 1 during the present eruptive cycle. This is because the volcano has already passed through the explosive phase in the present eruptive cycle.

Statistically, winds flow from Mount St. Helens toward Trojan 1 percent of the time. The five largest ash flows in the last 4,500 years favored wind directions to the north and east (Crandell and Mullineaux, 1978). As noted previously, however, a thin layer of ash possibly originating from a much older ash eruption of Mount St. Helens is reported in the Willamette Valley (Glenn, 1965).

The approximate chances of a maximum credible ash event may be on the order of one in 4×10^6 or 4×10^7 years (1/40,000 years $\times$ 1/100 [prevailing wind direction] $\times$ 1/10 [configuration of active vent]). Lesser ash falls with greater chances of occurring might also be of concern for the safe management of the plant. Using the data of Crandell and Mullineaux (1978), it can be shown that a 3-in (8-cm) event at Trojan may have a probability of one chance in 5×10^5 to 5×10^6 years. In both cases, precursor activity would precede the event.

Based on the geologic record and the statistical spread of wind direction to the east, it is concluded in general terms that a maximum credible ash fall will be equivalent to layer Yn of 4,000 years ago, with an accumulation of 24 in (30 cm) of ash at a distance of 30 mi (50 km), and that the plume will be directed to the east. The probability that a maximum credible eruption could be directed toward the Trojan site is very slight, especially in the present eruptive cycle. Lesser eruptions of higher probability could also impact the site but would be more manageable and would be preceded by significant precursor activity.

Pyroclastic flows

Masses of hot dry rock fragments mixed with hot gases traveling downslope as though they were fluid are called pyroclastic flows. They are very mobile because of gravity and the explosive force of the eruption and their rapidly expanding gases. The rapid discharge of gas converts rock material to ash-size particles, and the expanding cloud then assimilates and transports hot but not fused blocks, boulders, and smaller fragments downslope.

Pyroclastic flows can form in several ways: (1) Large pyroclastic flows can form from an explosive eruption at an open vent as parts of the eruption column fall back onto the flanks. They are characterized by flow downslope guided somewhat by topography. (2) Explosive activity at the base of a dome can expel moderate to large amounts of pumice and gas-charged fragments laterally. (3) Portions of a steep-sided dome that is building may collapse to send a mass of incandescent rock and finer debris cascading or exploding to lower elevations.

Pyroclastic flows are characterized by high temperatures and high velocities between 30 and 90 mi (50 and 150 km) per hour. Hazards may extend up to 6 mi (10 km) or more from the vent, as seen historically at Mt. Pelée, Mt. Vesuvius, Mt. Katmai, and Mount St. Helens. The pyroclastic flows of Mount St. Helens are well preserved in the geologic record and have been well studied and described in the literature (Crandell and Mullineaux, 1973; Hyde, 1975; Crandell and Mullineaux, 1978; Hoblitt and others, 1980). Consideration of the known geologic record of pyroclastic flows at Mount St. Helens provides a good basis for assessing future events.

Prior to the eruption of May 18, 1980, Crandell and Mullineaux (1978) predicted that nearly all areas within 3.5 mi (6 km) of the base of the volcano and locations in major drainages within 6 mi (10 km) of the base could be affected by future pyroclastic flows. Incorporation of water into the flow could generate hot mudflows that travel to greater distances.

The initial eruption of May 18, 1980, and later eruptions at Mount St. Helens produced many pyroclastic flows, primarily through partial collapse of the erupting ash column. Most were channeled to the north by the shape of the vent area. The initial eruption was a combination of lateral blast and pyroclastic flow and, as described previously, devastated a large area north of the cone.

The present configuration and eruptive phase of the volcano indicate that small to moderate pyroclastic flows may occur and they will be directed to the north. A maximum credible event exclusive of lateral blast could extend 6 mi (10 km) down major drainages but probably will not occur in the present eruptive cycle. Damage at greater distances is possible if pyroclastic material incorporates large amounts of water, and this type of phenomenon is discussed in the following section on mudflows. The distance from the Trojan site to any source of pyroclastic flows all but precludes any danger from this type of volcanic eruption.

Mudflows

When significant amounts of water become incorporated into moving volcanic material, a mudflow is generated. Mudflows may originate from (1) the release of water from a crater lake, (2) rapid melting of snow or ice under extensive pyroclastic flows, (3) explosive introduction of volcanic material into bodies of standing water, (4) descent of pyroclastic flows into river channels, or (5) collapse of an unstable volcanic cone resulting in a saturated avalanche or introduction of the collapsing material into bodies of water downslope. Speeds depend on slope and water content and may approach 20 to 30 mi (30 to 50 km) per hour. At Cotopaxi volcano in Ecuador, velocities of 50 mi (80 km) per hour were achieved. At Bezymianny volcano in Kamchatka, mudflows traveled a distance of 50 mi (80 km) beyond the base of the volcano in 1956.

During the 4,500-year recent history of Mount St. Helens, pyroclastic flows and mudflows have occurred on all flanks of the volcano, traveling distances of at least 20 mi (30 km) down the Swift Creek-Lewis River drainage, 40 mi (70 km) down the Toutle and Cowlitz Rivers, and 27 mi (45 km) down the Kalama River (Crandell and Mullineaux, 1978). In the preceding eruptive period (4,500 to 40,000 years B.P.), the largest event recognized to the south of the volcano extended 14 mi (24 km) down the Lewis River (Hyde, 1975) to Woodland, Washington. Volumes of these pyroclastic flows and mudflows are not known, although general geographic distributions are well established (Crandell and Mullineaux, 1978).

Mudflows of volcanic origin at Mount St. Helens appear to have generally formed by the introduction of volcanic material onto snow-covered slopes or into river channels. Melting of snow and glacial ice by increasing near-surface heat may also have been a factor. It is not always possible to determine the way mudflows in the geologic record were formed, although a careful examination to reveal bombs or other once-hot materials can suggest that pyroclastic flows were involved.

On some volcanoes, mudflows have been started by landsliding not directly related to volcanism. However, the relative freshness of the rocks high on the flanks and summit area of Mount St. Helens and the lack of clay minerals make these materials less prone to cause landslides and eventually mudflows. Also, post-eruptive lakes formed when debris avalanches or pyroclastic flows dam creeks or rivers can often introduce large quantities of water into loose materials when the dam is breached, thereby initiating another type of mudflow.

The geologic record and present physiographic condition of Mount St. Helens suggest that emphasis should be placed on investigating the probable mudflow hazard from the introduction of pyroclastic material into rivers or lakes or the eruption of large pyroclastic flows onto snow-covered slopes. At least two lakes of significant size (Coldwater and Castle Creek Lakes) also have formed as debris avalanches and lateral blast deposits dammed stream channels. These will be discussed in more detail in the section on flooding.

Stream channel mudflows: The major mudflows generated by the debris avalanche, lateral blast deposits, and pyroclastic flow deposits of the May 18, 1980, eruption were of large volume and occurred in all the main river systems around Mount St. Helens except that of the Kalama River. Immediately following the eruptions, mudflows moved rapidly down Smith Creek, Muddy River, and Pine Creek and into the Swift Reservoir and in 3 hours dumped 11,000 acre ft (14×10^6 m^3) of water, mud, and debris in the upstream area of the reservoir (Cummans, 1981). Concurrently, mudflows developed in the upper reaches of the South Fork Toutle River and traveled about 27 mi (45 km) in 90 minutes. In 2 hours, the 12-ft (3.5-m)-high wall of saturated debris reached the confluence with the North Fork and by 1 p.m. (5 hours) had entered the Cowlitz River. The specific gravity of the mudflow at Castle Rock was 2.1, with estimated flow rates of 120,000-170,000 cfs (Kienle, 1980).

The much larger North Fork Toutle River mudflows took somewhat longer to develop. High-water marks on the northeast arm of Spirit Lake indicate that much of the water was temporarily displaced by the debris avalanche and suggest that part of the water in the mudflow was derived from Spirit Lake. In addition, melting snow and glacial ice from the slopes of Mount St. Helens undoubtedly provided much of the water for the mudflow. The debris avalanche and pyroclastic flows formed a huge, 17-mi (27-km)-long deposit at least 400 ft (120 m) deep at the upper end near Spirit Lake and about 150 ft (45 m) deep at the downstream end near Elk Rock. The North Fork mudflow in some places crested nearly 30 ft (10 m) higher than the South Fork flow. The mudflow arrived at the Cowlitz River in about 8 hours, where it was homogeneous and of mortarlike consistency from bank to bank. Cummans (1981) gives details of peak flow, velocities, and time tables.

Portland General Electric Company (1980) shows that rerouting of the location of the 1980 Toutle River pyroclastic-mudflow event down the Lewis River would yield 30 million yd^3 (23 million m^3) of sediment in the Columbia River. Routing it down the Kalama River would yield 6.5 million yd^3 (5 million m^3) in the Columbia River.

Crandell and Mullineaux (1978) suggest that a significant mudflow event occurred about 3,000 years B.P. Thick pyroclastic-mudflow and fluvial deposits from this event filled the North Fork Toutle River valley to a depth of at least 50 ft (15 m). The flow extended down the Toutle and Cowlitz Rivers to Castle Rock and included distal fluvial deposits. Conceivably this event was related to the P event, but this relationship has not been demonstrated. It also corresponds in time with an abrupt, 60-ft (18-m)-deepening of Spirit Lake. The event in total extent may have been larger than that of May 18, 1980. Given the nature of the geologic record, it provides a fairly good measure of a maximum credible event in terms of mudflow extent. Such an event would be preceded by a wide variety of diagnostic precursors.

Mudflows of pyroclastic flow origin: A mudflow resulting strictly from ash-cloud phenomena might in a maximum case be expected to cover 10 mi^2 (26 km^2) of snow-covered terrain with 15 ft (4.5 m) of water equivalence (Newhall, 1981). This translates into a volume of material that would displace 96,000 acre ft (115 million m^3) of water. This compares to a total capacity of 756,000 acre ft (920 million m^3) for Swift Reservoir. Crandell and Mullineaux (1978) suggest that the largest single mudflow that might be expected to develop on the south flank of Mount St. Helens and subsequently enter the Swift Reservoir would have a volume of no more than 100,000 acre ft (125 million m^3).

Pacific Power and Light Company (1980), in evaluating the future probable events that might affect generating projects on the Lewis River, has determined that future eruptions might occur over a period of years, with little likelihood of a lateral blast to the south. The most likely event to cause problems to Swift Reservoir in the short term is a fallback-type pyroclastic flow that would cause rapid melting of some or all of the remaining ice or snow pack on the mountain, followed by floods or mudflows entering Swift Reservoir. They estimate that a pyroclastic flow could reach the Swift Reservoir dam and powerhouse with high enough temperatures to damage unprotected electrical and control equipment. They suggest that because 1,300 ft (400 m) is missing from the summit area of the mountain the overall drainage area of Swift Reservoir has been reduced considerably. As the missing areas were formerly those of greatest snow cover, Crandell and Mullineaux's (1978) model may no longer be valid. More refined calculations (Pacific Power and Light Company, 1980) based on the modified topography and assumed lesser water content of the mudflow indicate a realistic maximum volume that could occur in the future at the Swift Reservoir to be 50,000 acre ft (63 million m^3). This type of mudflow is equivalent in volume to about 20 percent of the volume of the Toutle River pyroclastic flow and associated sediments of the May 18, 1980, eruption.

Summary: A maximum credible pyroclastic-mudflow event involves generation of pyroclastic material of volume equivalent to the Toutle event of 2,500-3,000 years B.P. Included in the event is fluvial deposition of volcanic debris downstream along major river channels during and after the eruption, as occurred with the May 18, 1980, event. A maximum credible pyroclastic event might also involve a mudflow component similar to that modeled by Crandell and Mullineaux (1978). Finally, these volumes of material can conceivably be routed down any channel, although the present topography strongly favors routing down the Toutle River, at least in the present eruptive cycle. Because the event of 1980, which was of lesser size, impacted the channel of the Columbia River, it is evident that this maximum credible event would also affect the channel. It is therefore a consideration in terms of the cooling-water intake for the Trojan nuclear power plant. An event of this type, however, would be preceded by a variety of significant precursors.

The destruction of much of the cone in the eruption of May 18, 1980, will favor by 10 to 1 the direction of future pyroclastic flows and mudflows to the north until the volcano rebuilds its summit or until a new vent becomes activated; neither of these possibilities appears likely in the present eruptive cycle. In addition, the chance of a maximum credible event occurring within the present eruptive cycle is remote (one chance in ten) in view of the nature of this and prior ash eruptions of Mount St. Helens. For the sake of discussion, one might tentatively conclude that a maximum pyroclastic eruption has one chance in 4×10^6 of occurring in any given year: (1/40,000 years $\times$ 1/10 [topographic factor] $\times$ 1/10 [eruptive phase factor]).

An event of lesser magnitude, such as the pyroclastic flow of May 18, 1980, will occur more often and might be expected to occur once every 500 years or so, given the geologic history of the volcano. Application of the topographic and eruptive phase factors (both viewed by the authors as very conservative) yields an annual probability of one chance in 50,000. It is this type of event that is modeled by Portland General Electric Company (1980) and for which it is demonstrated that no flood hazard exists for Trojan, given the conservative scenarios accommodated by the FSAR (Portland General Electric Company, 1976). No such event has occurred in the life of the vent, although Mount St. Helens mudflows have extended as far as Woodland, Washington. If such an event were to occur, then siltation could impact the primary source of cooling water for Trojan. It is not presently possible to quantify this impact.

Flooding

Flooding related to volcanic activity at Mount St. Helens can be a product of rapid snowmelt under volcanic deposits, modified streamflow during a pyroclastic eruption, postulated dam failure along Swift Creek and the Lewis River arising from mudflows and pyroclastic flows, modified infiltration rates, or modified channel geometry. Other catastrophic floods can be postulated in the event of failure of debris dams which retain newly-formed lakes such as Coldwater Lake and Castle Creek Lake. In addition, volcanic debris routed down the channels of rivers through normal fluvial processes may also be a consideration to the facility.

By their nature, floods of the scale considered here are generally not amenable to complete preservation in the geologic record and must be interpreted on the basis of the historic record or hydrologic analysis. The Final Safety Assessment Report (FSAR) (Portland General Electric Company, 1976) models and analyzes a wide variety of hypothetical floods and adequately demonstrates that sequential dam failures along Swift Creek and the Lewis River do not pose a threat to the Trojan nuclear power plant. Crandell and Mullineaux (1978) show that the largest single mudflow they would expect in the Swift Creek drainage could be easily accommodated by the storage capacity of Swift Reservoir. Pacific Power and Light Company (1980) demonstrates that a maximum possible mudflow into Swift Reservoir may now be only 50,000 acre ft (63 million m^3), as opposed to the 100,000 acre ft (125 million m^3) of Crandell and Mullineaux (1978), owing in part to the greatly modified topography of the present vent.

Kienle (1980) describes the May 1980 mudflows of Mount St. Helens, enumerating at least five surges of debris or distinct mudflows and muddy floods down the North Fork of the Toutle River into the Cowlitz and then the Columbia Rivers. During each surge, the Cowlitz River level was raised as far south as the Kelso-Longview, Washington, area, 112 river mi (180 km) from the mountain. At Rainier, Oregon, the Columbia River level was raised 4.5-6.5 ft (1.5-2.0 m) during May 18 and 19, 1980.

In response to a query from the U.S. Nuclear Regulatory Commission, a Portland General Electric Company (1980) letter report presents a map showing the potential extent of mudflows and flooding in the Lewis and Kalama River drainages. This map shows mudflows extending to within about 5 mi (8 km) of the Kalama River mouth, which is directly across from the Trojan plant. The flood wave calculated to be generated by the mudflow in the Kalama drainage would be about 6 ft (2 m) high at its confluence with the Columbia. The map also shows pyroclastic-mudflows entering the Swift Reservoir via Swift Creek, overtopping or causing postulated dam failure for Swift Reservoir, with postulated subsequent failure of Yale and Merwin Dams. The calculated flood wave from this event would reach Woodland, Washington, in about 1 hour and would inundate areas to a height of 36-40 ft (11-12 m) MSL (mean sea level). This model further predicts the Lewis River flood wave to reach Rainier, Oregon, in about 3 hours, with a peak elevation of 36 ft (11 m) MSL. Neither of these flood waves would reach the design elevation of the Trojan plant. Thus, floods generated by maximum credible mudflows or by actual dam failure in the Lewis River drainage are accommodated by the original siting criteria of the facility.

An additional kind of flooding with possible ramifications to Trojan is the failure of debris dams behind which are located newly impounded lakes, such as Coldwater or Castle

Creek Lakes, within the Toutle River drainage. The lake in Coldwater Creek is the greatest threat. According to Dunne and Leopold (1980), storage capacity of the lake to an elevation of 2,510 ft (766 m) (height of the debris dam) is 100,000 acre ft (125 million m^3). Assuming failure with a rate of downward erosion of 1 ft (0.3 m) per minute, horizontal erosion of 2 ft (0.6 m) per minute, and characteristics of failure analogous to that of the Teton Dam in Idaho, a maximum discharge of 475,000 cfs will occur 100 minutes after the original breach (Dunne and Leopold, 1980).

The volume of water discharging from the breach, if doubled to accommodate the incorporation of silt, sand, and debris and routed down the Toutle River to its mouth using standard routing procedures, yields a discharge at the mouth of 500,000 cfs. This would be more than twice the discharge of the May 18, 1980, North Fork mudflow at Silver Lake and compares to a discharge on the same day of 120,000-170,000 cfs downstream at Castle Rock, Washington. It should be noted that a bedrock drain to prevent the overflow of Coldwater Lake has been completed, and similar corrective measures have been started at Castle Creek Lake.

If, however, the Coldwater or Castle Creek Lakes dams did fail, the discharge at the mouth of the Cowlitz River downstream from the Trojan facility would be less—and far less than the discharge of 3 million cfs for which the facility is adequately designed. The significance of the event lies in the potential for silt deposition in the channel of the Columbia River. As noted by Dunne and Leopold (1980), the discharge would be twice that of the May 18, 1980, eruption, during which siltation did occur at Trojan.

In summary, maximum credible floods arising from pyroclastic flows, mudflows, dam failures, or failure of debris dams are more than adequately accommodated by the more conservative flood scenarios of the FSAR (Portland General Electric Company, 1976). Possible siltation of the channel of the Columbia River associated with the flooding of various river channels including the Cowlitz River could conceivably affect the channel at Trojan, given the experience of the eruption of May 18, 1980. Given the complexity of channel erosion in tributaries to the Columbia River and our presently incomplete understanding of potential depositional patterns in the Columbia River, quantification of siltation is not possible here.

Conclusions

1. Our reasonably complete understanding of the moderate- to large-scale past volcanic activity of Mount St. Helens justifies use of the concept of maximum credible event in assessing future risk. This approach generally is more reasonable than a strictly quantitative approach for volcanic hazards.

2. The maximum credible lateral blast does not pose a threat to the Trojan site. Further, any significant blasts are of low probability in the present eruptive cycle and would be directed to the north by the present crater topography. Precursors of any lateral blasts will include significantly increased seismicity, deformation, and probably bulging.

3. The maximum credible ash fall could deliver 24 in (60 cm) of ash to the Trojan site in a period of a few days. Such an event has not occurred at the Trojan site in the 40,000-year history of the vent and, in the present eruptive cycle, has an estimated yearly probability of perhaps only one chance in 4×10^6 to 4×10^7. Seismicity, deformation, and tilt precursors would precede such an event.

4. A lesser ash fall event could deliver 3 in (8 cm) of ash to the Trojan site also in a period of a few days. Such an event has not occurred at Trojan in the 40,000-year history of the vent to our knowledge and, in the present eruptive cycle, has an estimated probability of perhaps one chance in 5×10^5 to 10^6. Seismicity, deformation, and tilt precursors would precede such an event.

5. Pyroclastic flows will be restricted to regions within 3.6 mi (6 km) of the base of the volcano with the exception of major valleys, where maximum extents of 6-9 mi (10-15 km) are possible; the potential for large pyroclastic flows in the present eruptive cycle is small, and those that may occur will probably be directed to the north by vent topography.

6. A maximum credible mudflow would be equivalent to the Toutle River event of 3,000 years B.P. and could possibly exceed the event of May 18, 1980. It conceivably could be routed down any river channel, although present topography of the mountain strongly favors routing to the north. Given the fact that the May 18, 1980, event delivered sediment to the Columbia River channel near the Trojan plant, it is concluded that a maximum credible event could impact the channel at the cooling-water intake facility. Such an event probably would not occur in the present eruptive cycle and would be preceded by significant seismic, deformation, and tilt precursors.

7. Maximum flooding potential arising from volcanic activity is adequately accommodated in more extreme flood scenarios presented in the original flood design considerations of the facility. A related potential impact may be concurrent sedimentation near the cooling-water intake structure.

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AIME annual dinner to be held in Portland

The Oregon section of the American Institute of Mining, Metallurgical, and Petroleum Engineers will hold its annual dinner on Thursday, December 17, at the Flamingo Restaurant, 9727 N.E. Sandy Blvd., Portland. Al Rule, U.S. Bureau of Mines, will speak on the current status of Chinese research equipment for phosphate ore processing which he observed during his recent trip to China. Social hour will be at 6 p.m., dinner at 7 p.m., and talk at 8 p.m. Reservations are required. For more information, contact Mike York, Accident and Failure Investigations, Inc., 2107 N.W. Fillmore, Corvallis; phone (503) 757-0349. For reservations, contact Mike York or the Portland office of the Oregon Department of Geology and Mineral Industries; phone (503) 229-5580. The public is invited. □

GSOC luncheon meetings announced

The Geological Society of the Oregon Country (GSOC) holds noon meetings in the Standard Plaza Building, 1100 SW Sixth Avenue, Portland, in Room A adjacent to the third floor cafeteria. Topics of upcoming meetings and speakers include:

December 18—*Giants of the Geological Society of the Oregon Country: Edwin T. Hodge, Albert Dunbar Vance, and Alonzo (Lon) Wesley Hancock*; by Arthur C. Jones, M.D.

January 15, 1982—*Plant and Animal Fossils*: by Leo F. Simon, photographer, retired, and president 1949.

For additional information, contact Viola L. Oberson, Luncheon Chairwoman, phone (503) 282-3685. □

Correction:

The third line in the section on "OIL AND GAS DRILLING" in the article entitled "State legislation affecting mineral industry summarized" on page 151 in the November 1981 *Oregon Geology* has an error. "ORS 522" should be changed to "ORS 520" so that the sentence reads: "House Bill 2146 provides several administrative changes to the Oregon oil and gas conservation law (ORS 520) and streamlines the existing law with respect to drilling of wells." □

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