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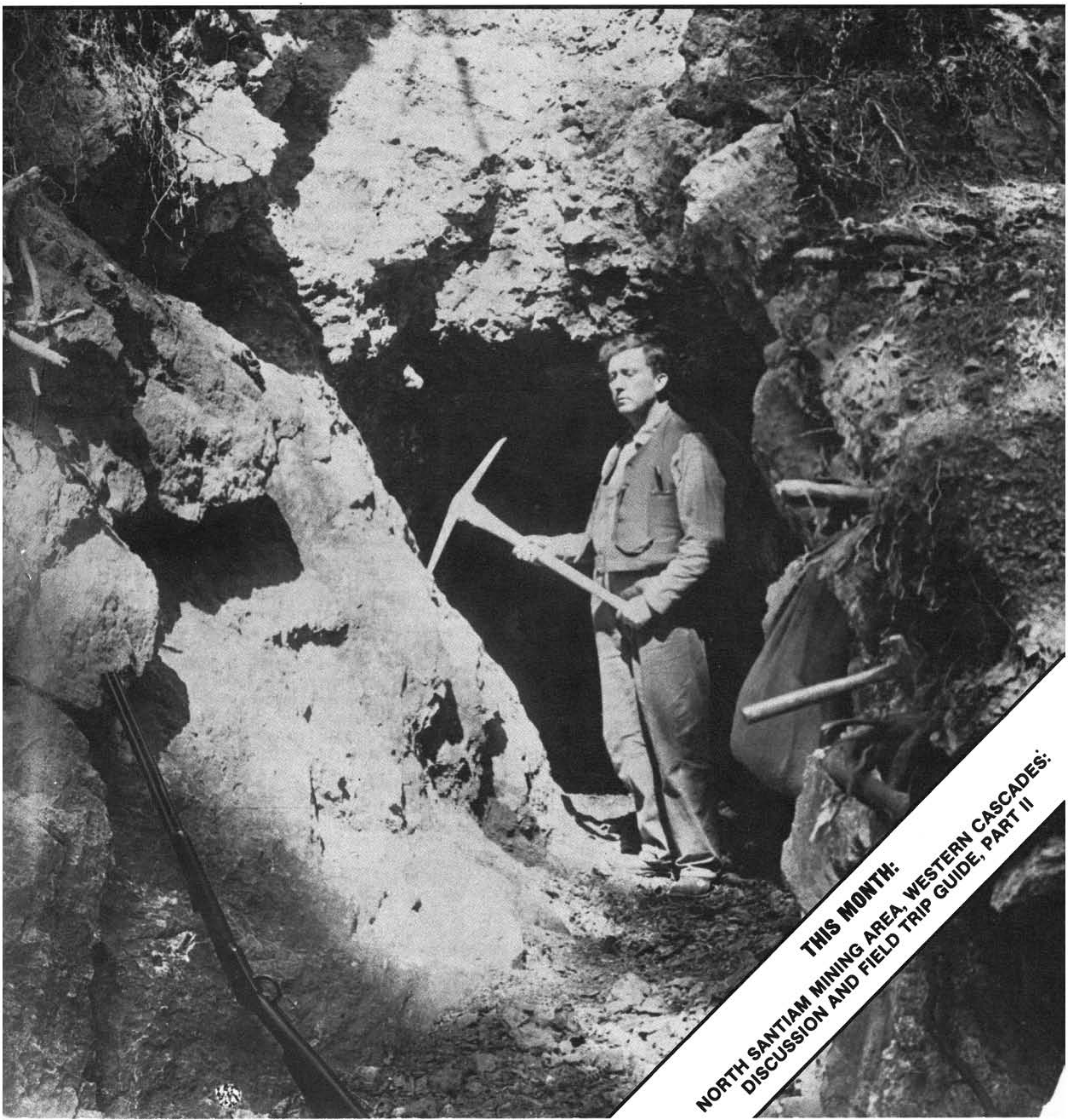

THIS MONTH:

NORTH SANTIAM MINING AREA, WESTERN CASCADES: DISCUSSION AND FIELD TRIP GUIDE, PART II

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

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

COVER PHOTO

Typical early-day mine adit and miner. Photo was taken in the Blue River mining district in the Western Cascades, south of the North Santiam area, which is the subject of field trip guide beginning on next page. Photo courtesy Oregon Historical Society.

OIL AND GAS NEWS

Columbia County — Mist Gas Field

ARCO Columbia County 22-27, located in NW¼ sec. 27, T. 6 N., R. 5 W., in the vicinity of five recent gas completions, was spudded November 17, 1985, drilled to a total depth of 2,500 ft, and plugged and abandoned November 25, 1985.

ARCO Columbia County 32-32, located in NE¼ sec. 32, T. 6 N., R. 5 W., in the extreme west central part of the field, and 1¾ mi southwest of the nearest production, was completed November 13, 1985, as the 21st producing well in the field and ARCO's second success there this year. The well was drilled to a total depth of 2,711 ft.

ARCO Crown Zellerbach 23-15, located near Pittsburg in the extreme southeast part of the field in SW¼ sec. 15, T. 5 N., R. 4 W., was spudded November 26, 1985, and is drilling toward a permitted total depth of 3,500 ft. This well is just southeast of ARCO Crown Zellerbach 31-16, the most southeasterly producing well in the field.

ARCO Crown Zellerbach 41-2, located in NE¼ sec. 2, T. 5 N., R. 5 W., was spudded November 5, 1985, drilled to a total depth of 2,109 ft, and plugged and abandoned November 12, 1985.

ARCO Longview Fibre 23-25, located in SW¼ sec. 25, T. 6 N., R. 5 W., was spudded December 1, 1985, and is drilling toward a permitted total depth of 2,100 ft.

Columbia County — Wildcat

Exxon GPE Federal Com. 1, located in sec. 3, T. 4 N., R. 3 W., 2 mi north of Chapman in south-central Columbia County, was spudded September 2, 1985, and plugged and abandoned November 8, 1985. Permitted total depth was 12,000 ft. Total depth reached has not been released by the operator.

Lincoln County

Damon Petroleum Longview Fibre 3, located in NW¼ sec. 21, T. 9 S., R. 11 W., was spudded September 27, 1985, drilled to a total depth of 3,040 ft, and plugged and abandoned November 16, 1985. This is the third well drilled in this immediate vicinity since 1980. None have found production.

Production: Mist Gas Field

Cumulative: (1979-1984): 19,219,335 Mcf
1985 Production (Mcf):

January	271,717	June	372,148
February	242,077	July	385,157
March	301,885	August	386,511
April	300,775	September	405,563
May	364,072		

Cumulative (1985): 3,029,905
Cumulative (1979-Sept. 1985): 22,249,240 Mcf

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
341	ARCO Longview Fibre 41-35 009-00182	NE¼ sec. 35 T. 6 N., R. 5 W. Columbia County	Location; 1,900.
342	ARCO Columbia County 31-27 009-00183	NE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Location; 2,115.
343	ARCO Longview Fibre 34-25 009-00184	SE¼ sec. 25 T. 6 N., R. 5 W. Columbia County	Location; 2,020.

□

North Santiam mining area, Western Cascades — relations between alteration and volcanic stratigraphy: Discussion and field trip guide

by J. Michael Pollock and Michael L. Cummings, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207

Part II. Field trip guide*

ROAD AND TRAIL LOG

The route of the trip is shown in Figure 1. Mileage is indicated in this log by italicized numbers. The first set of numbers is cumulative throughout the field trip; the numbers in parentheses indicate the mileage between points. The portion of the trip that goes through the Shiny Rock Mining Company claims is to be traveled on foot and is 4.7 mi each way. For your safety, avoid open mine adits. Most are not maintained and are unstable and very dangerous.

0.0 mi (0.0 mi) Proceed east on Oregon Highway 22 from its intersection with Interstate I-5 (exit 253) on the southeast edge of Salem. The highway climbs out of the Willamette Valley into the Waldo Hills. These hills, the Salem Hills to the southwest, and the Eola Hills west of Salem are underlain by flows of the Columbia River Basalt Group (CRBG).

Thayer (1939) originally named these basalts the Stayton lavas, indicated that the rocks were similar to the CRBG, and tentatively correlated them with the CRBG. M. Beeson (oral communication, 1984) confirmed that the Stayton lavas are actually flows of the CRBG.

Tolan and others (1984), in their studies of the Neogene history of the Columbia River, indicated that the oldest identified channel of the Columbia River passed near Stayton, through the Salem Hills, and possibly west to the Pacific Ocean. This channel developed during "Vantage time," a period of time lasting for several hundred thousand years or longer between the last eruptions of CRBG flows of the Grande Ronde Basalt (15.5 m.y. ago) and the first eruptions of the Frenchman Springs Member of the Wanapum Basalt. The first flow of the Frenchman Springs Member to reach this area, the Ginkgo flow, followed this ancestral channel. Hoffman (1981) reported the thickness of the Ginkgo flow in the southeastern Salem Hills as 180 m.

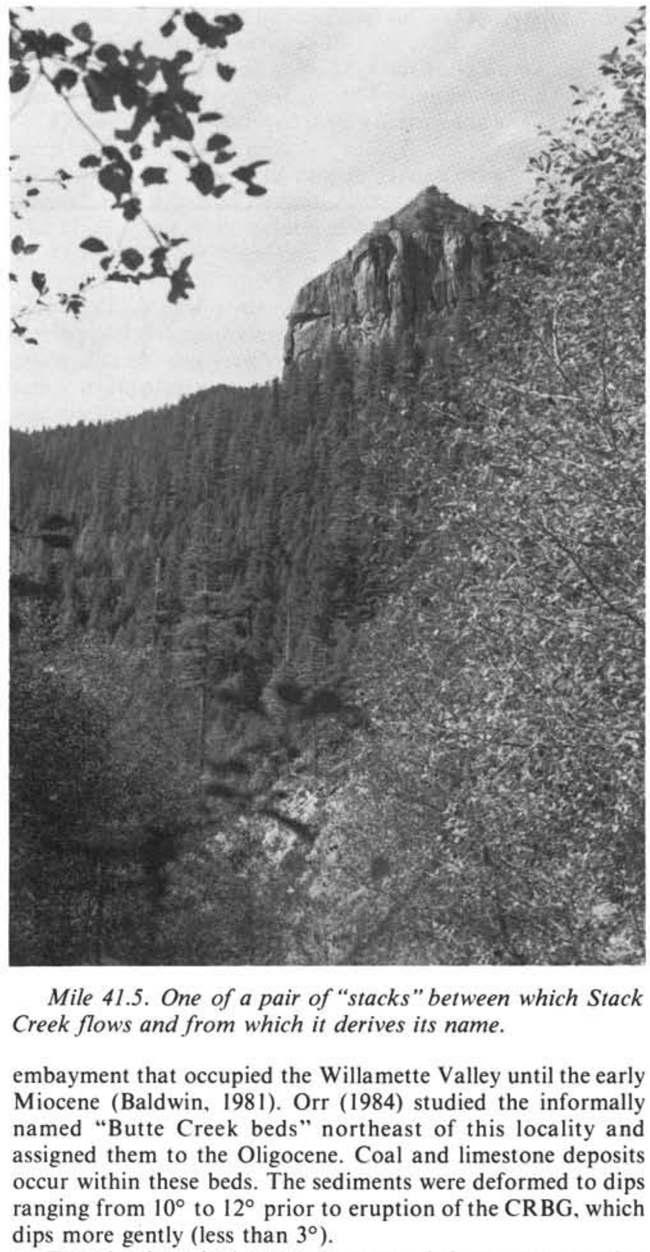
As the road climbs the hills, note the red-colored laterite soils developed on these basalts. In the Salem Hills, ferruginous bauxite deposits have developed from the Frenchman Springs Member (Hoffman, 1981). These bauxite deposits are iron-rich and, in the Salem Hills, contain 13.4 million dry long tons of ore at 36.02 percent Al_2O_3; 4.17 percent SiO_2; and 32.49 percent Fe_2O_3 (Hook, 1976).

4.0 mi (4.0 mi) View to the east from the crest of the Waldo Hills toward the Cascade Range. The snow-covered peak in the distance is Mount Jefferson, one of the composite volcanos of the late High Cascade group of Priest and others (1984). Most of the hills in the intermediate distance are composed of rocks of the Western Cascade group of Priest and others (1984).

12.3 mi (8.3 mi) Sediments exposed in small outcrops are of the Illahe formation as defined by Thayer (1939). These sediments, which underlie the CRBG, are well-bedded, tuffaceous marine sandstones that were deposited in a marine embayment that occupied the Willamette Valley until the early Miocene (Baldwin, 1981). Orr (1984) studied the informally named "Butte Creek beds" northeast of this locality and assigned them to the Oligocene. Coal and limestone deposits occur within these beds. The sediments were deformed to dips ranging from 10° to 12° prior to eruption of the CRBG, which dips more gently (less than 3°).

Examination of this outcrop reveals distinct reverse grading (finer particles near the base and increasing in size toward the tops of individual beds) resulting from the tendency of pumice to float. Also present are abundant carbonized and uncarbonized plant materials.

14.5 mi (2.2 mi) Flows of the CRBG are exposed to the right and left of the highway as the road descends a small hill north of the town of Stayton. The road to the right enters Stayton, and in a quarry along the road, andesitic volcanic rocks that may be the



Mile 41.5. One of a pair of "stacks" between which Stack Creek flows and from which it derives its name.

*Part I, discussion, and references for both parts appeared in last month's issue (December 1985).

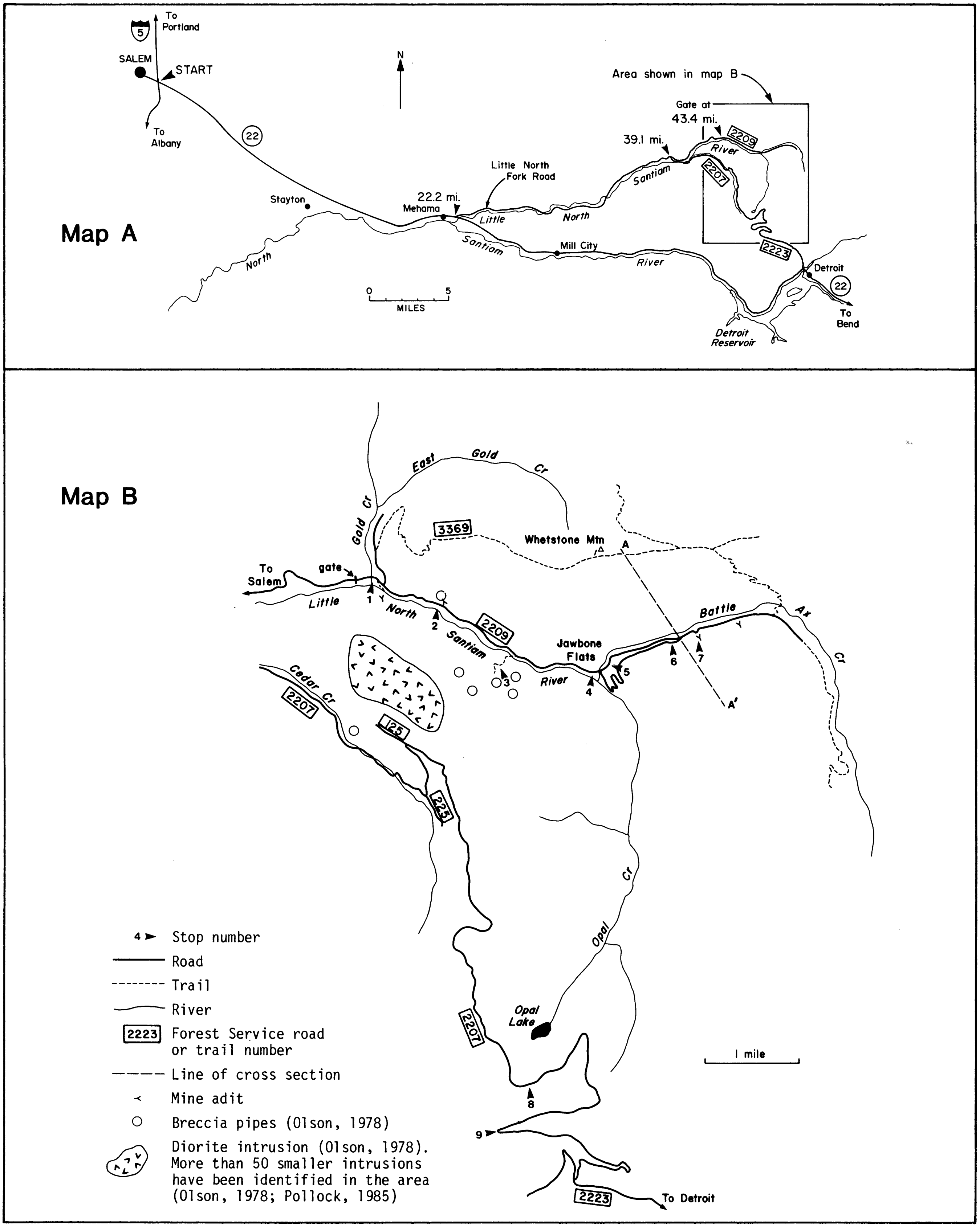


Figure 1. Map A. Route of field trip to North Santiam mining area, Oregon. Map B. Locations of key geologic features and field trip stops.

Mehama volcanics of Thayer (1936, 1939) are exposed.

21.4 mi (6.9 mi) Mehama-Lyons junction. *Continue on Highway 22 for 0.8 mi.*

22.2 mi (0.8 mi) Intersection with Little North Fork Road to the Little North Santiam Recreation Area along the Little North Santiam River. *Turn left (northeast).* The Little North Santiam River joins the North Santiam River immediately south of this intersection. Upper slopes of hills in this area are flows of the CRBG.

25.2 mi (3.0 mi) Exposures of a basalt intracanyon flow are located to the left on the north side of the road. The source of the basalt is not known. It is not basalt of the CRBG (M. Beeson, oral communication, 1984) but may be a flow from a High Cascade basalt shield volcano. The intracanyon flow can be observed at several localities along the road up the valley, suggesting that the ancestral Little North Santiam River was located in approximately its present location at the time the flow was erupted.

27.2 mi (2.0 mi) The irregularity in the road surface is due to active landslides. Deeply weathered volcaniclastic sediments in the cliff are involved in a particularly troublesome landslide. In the woods north of the road is the basalt intracanyon flow. Steep contacts between diverse volcanic units are commonly associated with slope failures.

28.3 mi (1.1 mi) BEWARE — the road takes a very tricky turn onto the bridge over the Little North Santiam River.

29.0 mi (0.7 mi) The basalt intracanyon flow is exposed in the quarry along the south side of the road. The jointing pattern is typical of the jointing developed in intracanyon flows.

33.6 mi (4.6 mi) Bridge over the Little North Santiam River. Rocks of the Mehama volcanics (Thayer, 1936, 1939) crop out along the river valley.

36.3 mi (2.7 mi) Entrance to Salmon Falls State Park.

37.3 mi (1.0 mi) Intersection with Evans Mountain Road. *Continue straight ahead on USFS Road 2209.* Evans Mountain is named for a mysterious prospector known as "Old Man Evans" who was found tortured and murdered on his claims. Local legend has it that Evans was finding sufficient gold to support an elegant life style. As in all such mining legends, the location of his "mother lode" has not been found. This legend and others of the area are recounted by Roberts (date unknown) in her book, *Elkhorn and Mehama: True Stories of Oregonians of the North Santiam*, which is usually available in the general store in Mehama.

38.4 mi (1.1 mi) Bridge over Henline Creek. North of USFS Road 2209 are abandoned workings on the Capital claim. The claim was patented as early as 1893. Most of the workings were caved by the 1930's. Veins have an average strike of N. 50° W. and dip of 75° to 80° SW. The veins are composed of a breccia of silicified andesite containing sericite and mesitite, an iron-magnesium carbonate. The breccia is cemented with stringers and veinlets of quartz with sulfides, chiefly sphalerite. There is minor galena and chalcopyrite (Callaghan and Buddington, 1938).

The Crown Mine, located to the south on the north flank of Elkhorn Mountain, was developed around 1927. Several veins were crossed in altered andesite, tuff, and volcanic breccia. A rhyolite is encountered near the contact of an intusive quartz diorite at the south end of the main crosscut. The Blind, Salem, Thirteen-Foot, and Winze Veins are along brecciated zones in which minor chalcopyrite, pyrite, and minor sphalerite are located within wall rocks mapped as tourmaline hornfels. These weakly mineralized veins strike from N. 55° W. to N. 60° W. (Callaghan and Buddington, 1938).

39.1 mi (0.7 mi) Intersection of USFS Roads 2207 and 2209. *Stay on USFS Road 2209 straight ahead at this intersection.* The road continues to follow the glaciated valley of the Little North Santiam River.

39.5 mi (0.4 mi) The area between this outcrop and the Ruth Mine was mapped by Olson (1978), who concentrated on the mineralization and alteration associated with breccia pipes in the area. Olson informally divided these rocks into upper and lower members of the Sardine Formation, and the lower member crops out along the road. The rocks in the major road cuts are andesite tuffs and contain accretionary lapilli, abundant lithic fragments, possible pumice fragments, and crystal clasts.

Epidote-lined fractures are present in the outcrop, and the common occurence of epidote in the tuffs is indicated by their yellow-green color.

39.7 mi (0.2 mi) The lithic-crystal tuff exposed in these road cuts contains accretionary lapilli.

41.5 mi (1.8 mi) Road crosses Stack Creek. To the north is a scenic view of the twin stacks on Henline Mountain.

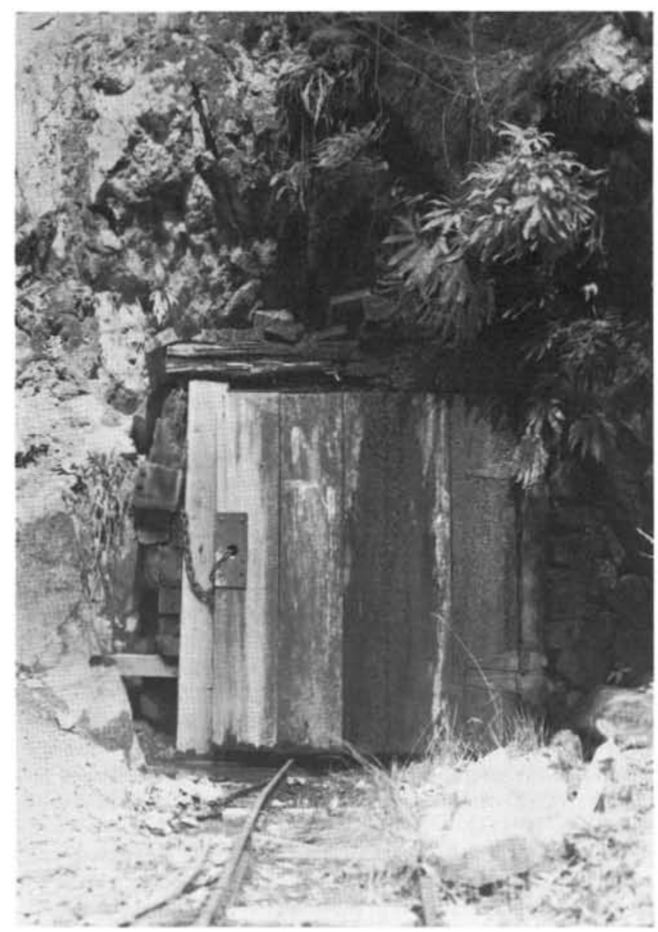
42.8 mi (1.3 mi) The road is very narrow and on the edge of a steep cliff into Horn Creek.

42.9 mi (0.1 mi) Road crosses Horn Creek after passing through a large pile of unconsolidated debris of glacial origin. The Black Eagle Mine is located at this point.

43.4 mi (0.5 mi) Gate at the west edge of the claim block controlled by the Shiny Rock Mining Company. *At this point park your car and proceed on foot. The Shiny Rock Mining Company is attempting to preserve the historic mining artifacts of the district, and your cooperation is appreciated. For your safety, avoid open mine adits, many of which are not maintained and are unstable.*

43.8 mi (0.4 mi) Bridge over Gold Creek.

43.9 mi (0.1 mi) **Stop 1.** A short side road leads to the adit of the Santiam 1 Mine on the Little North Santiam River. This



Stop 1. The adit of Santiam 1 Mine is one of hundreds of mine adits and prospects in the North Santiam mining area.

mine has also been known as the Minnie E. and the Lotz-Larsen at various times in its history. Most of the development work was done in 1915-1917, with some ore shipped in 1924. The vein strikes N. 43° W. and dips 50° to 80° NE. and has been mined on both sides of the river. Ore minerals are distributed along the vein, but there are four distinct narrow ore shoots. Chalcopyrite is the principal ore mineral; pyrite and sphalerite are subordinate. Ore grades ranged from 1.25 to 4.47 percent copper and 0.1 to 1.22 oz of gold per ton. Locally the vein was up to 35 cm wide and composed primarily of chalcopyrite (Callaghan and Buddington, 1938).

The waterfall developed where the altered rocks of the vein were less resistant than the surrounding rocks. When the water level is low, the vein can be seen on the downstream end of the plunge pool. Waterfalls are common throughout the district and serve as one means of locating veins.

Stop 1. The Minnie E. Vein on which the Santiam 1 Mine adit is located crosses the Little North Santiam River and has been mined on both sides. Waterfalls such as the one in this photo commonly form where streams are able to downcut easily into the altered rock of the veins.

44.0 mi (0.1 mi) Whetstone Mountain trailhead. The trail, which is not included as part of this log, proceeds north along Gold Creek and then east along the ridge to the top of Whetstone Mountain. This well-maintained trail makes a scenic side trip, but it is over 5 mi to the top and moderately steep, with no water. The top of Whetstone Mountain can also be reached from the Clackamas River drainage. Maps are available from the Ripplebrook Ranger Station.

44.3 mi (0.3 mi) **Stop 2.** Half bridge along the north bank of the Little North Santiam River. An intrusion of porphyritic diorite forms a prominent cliff. Phenocrysts up to 8 mm long of blocky- to prismatic-shaped plagioclase comprises 15 percent of the rock. The dike has vesicles that have been filled by quartz. Plagioclase is altered to epidote, and hornblende is replaced by chlorite. The dike intrudes a lithic-crystal tuff, and xenoliths are common along its margins.

44.4 mi (0.1 mi) The Golden Bear mine workings are in a vein of the Santiam group of claims. This adit is located in what Olson (1978) mapped as a tourmaline-bearing breccia pipe. The rocks are brecciated, silicified, and sericitized. An adit has been driven into the alteration for nearly 270 ft along a bearing of N. 35° W. (Oregon Department of Geology and Mineral Industries, 1951).

44.7 mi (0.3 mi) This porphyritic diorite intrusion was mapped by Olson (1978) as an intrusion genetically related to the large intrusion located in the center of the mining area and dated at 13.4 m.y. B.P. (Power and others, 1981a). This intrusion follows a N. 30° W. trend along its eastern margin but is strongly sheared on a N. 10° W. trend on its western margin. This same relationship occurs for the porphyritic diorite dike near the Level 5 portal of the Ruth Mine.

45.4 mi (0.7 mi) The collapsed buildings to the south of the road are part of the Merten sawmill built in 1943. Two steam-driven capstans believed to have been salvaged from the battleship *Oregon* were used in this mill and remain on the site (Cox, 1985). One of the storage sheds is still standing near the east end of the mill site.

45.6 mi (0.2 mi) **Stop 3.** *Take the side road that crosses the Little North Santiam River on an old bridge to the south of the main road.* This road leads to the site of holes drilled by Amoco Minerals under lease agreement with Shiny Rock Mining Company. These holes are located in a cluster of tourmaline breccia pipes mapped by Olson (1978). The pipes, which are intensely altered and circular to elliptical in plan, range from 10 to over 100 m in length. Olson (1978) defined two types of breccia pipes: (1) shatter breccias of highly fractured rocks partially or completely altered to an assemblage of tourmaline, quartz, and sericite; and (2) "characterized by highly-altered angular to subrounded clasts cemented by quartz, sericite, tourmaline, oxides, sulfides, and rarely carbonate." In the first type of breccia pipe, there was little or no movement of fragments; in the second, the clasts have been displaced within the breccia. Zones of hydrothermal alteration extend 50 to 100

Stop 2. Half bridge, so called because the road is supported on one side by timbers and the other by the side of the valley, was required where the highly resistant rock of a large intrusion was encountered by the early miners in the North Santiam mining area.

m beyond the margins of the pipes. The last event in formation of the pipes was the filling of open-space veins with quartz.

Tourmaline occurs at this location as black rosettes, some of which surround chalcopyrite and are associated with secondary malachite. The best samples are found along the road and in small stream bed to the east. *Return to the main road.*

45.7 mi (0.1 mi) Lure No. 3 adit is developed beneath the level of the road. The rocks are brecciated and silicified. Rosettes of tourmaline occur in the silicified materials, and pyrite and chalcopyrite occur in the alteration zone.

46.6 mi (0.9 mi) **Stop 4.** Jawbone Flats, Oregon. This historic mining camp was built in the early 1930's and still serves as the operational headquarters for the mining activities in the district. *Please stay out of the buildings and away from equipment, and respect the historic artifacts that are present. On the east end of Jawbone Flats, a bridge crosses Battle Ax Creek about 0.25 mi north of where it joins Opal Creek to form the Little North Santiam River. Just across the bridge, a side road leads a short distance to the ore mill currently used by Shiny Rock Mining Company for processing ore from the Ruth Mine. Return to the main road.*

Stop 4. Jawbone Flats was constructed in 1932 as a mining camp and still serves as the operational headquarters for mining activity in the eastern portion of the North Santiam mining area. Of the 30 or so original buildings, about half are still in use.

46.8 mi (0.2 mi) **Stop 5.** At this site are the ruins of the original ore mill constructed by the Amalgamated Mining Company in 1932. This mill collapsed under heavy snows in 1949 (George, 1985). The original steam generator and other equipment are still visible. On the right side of the road was the old ore stockpile, and samples of ore from several of the veins in this part of the district can be found in this pile.

47.1 mi (0.3 mi) An unmarked trail leads to the left. This was an old tram road used to haul ore from the Ruth Mine to the mill. *Stay on the main road.*

47.5 mi (0.4 mi) A side road joins the main road at a sharp angle. In the stream bed of Battle Ax Creek below this point are several veins and adits of the Bueche Group of claims. The ruins of an old building are located on the north side of the road. *Stay on the main road.*

47.9 mi (0.4 mi) **Stop 6.** The road crosses a small tributary of Battle Ax Creek. Exposed in the road cut to the west of the creek is an outcrop of a quartz-feldspar porphyry intrusion. The rocks are nearly white in color, with an abundance of quartz and feldspar phenocrysts. To the east of the creek, an intrusion of equigranular diorite intrudes a tuff of Unit A. The creek is located on a fault, and alteration along this fault is visible in both intrusions. At the level of the tram road visible below, float from a collapsed adit suggests that this vein contains more

Stop 4. This operating ore mill located just south of Jawbone flats was constructed in part from equipment salvaged from earlier mills in the mining area.

chalcopyrite than is common in veins this far east in the district.

48.0 mi (0.1 mi) Road intersection. The road to the right leads to the adit of Level 4 of the Ruth Mine. *Stay to the left.*

48.1 mi (0.1 mi) Road intersection. **Stop 7.** The road that turns sharply to the left leads down to Level 5 of the Ruth Mine while the main road continues a short distance to a small creek. *Follow main road to small creek.* This creek, which is commonly called Ruth Creek, is downcut on the Ruth Vein. Adits have been driven on five levels of this vein. The open adit visible above the road is the fourth level and is collapsed where it encounters the vein. It was a primary producer of ore in the 1930's. Ore was removed by ore cart and dumped into a loading chute that is now collapsed at the road level. Ore samples from this adit can be collected in the stream.

Return to the road intersection. Take the steep lower road down to Level 5 of the Ruth Mine. A small roadcut along this road is located in a porphyritic diorite intrusion that is strongly sheared on its west margin. *When you reach the level of the tram road, STOP.* To the right is Level 5 of the Ruth Mine. This adit is being actively mined at present. *BEWARE of mining activities, and stay out.* Below the adit in the creek bed, an intrusion of quartz-feldspar porphyry cuts a coarse block breccia of Unit A. Just downstream, a dike of porphyritic diorite is visible as a resistant unit.

This concludes the trail log. Return to the main road and to your car by the same route. You may then return to Salem by the same route or take the optional route over French Creek Ridge.

OPTIONAL TRIP BEGINS AT INTERSECTION OF USFS ROADS 2207 AND 2209

At road log mile 39.1, take USFS Road 2207 to the southeast. Note: USFS Road 2207 is a logging road and not regularly maintained. It may be impassable in bad weather.

3.3 mi (3.3 mi) Bridge over the Little North Santiam River. On private land north of the road, Amoco Minerals Company has discovered a mineralized breccia pipe. The pipe is exposed in small outcrops on the north bank of Cedar Creek. Although discovery and drilling on the prospect were underway in 1981, no public announcement has been made, and no published information on the pipe is available.

5.1 mi (1.8 mi) Road crosses Cedar Creek.

5.5 mi (0.4 mi) Intersection of USFS Roads 225 and 2207. *Remain on USFS Road 2207 to the left.*

6.0 mi (0.5 mi) Intersection of USFS Roads 125 and 2207. *Stay on USFS Road 2207 to the right.*

9.2 mi (3.2 mi) Epidote-lined fractures are seen to cut rocks of the Sardine Formation in the roadcuts. The North Santiam mining area is approximately 3 mi to the north. Signs of hydrothermal alteration are common in the area, and epidote-lined fractures and propylitic alteration are typically noted.

10.2 mi (1.0 mi) A large dike crops out near where the road swings to follow the cirque wall to the east.

10.4 mi (0.2 mi) **Stop 8.** Overlook of Opal Lake, the headwaters for Opal Creek, which joins Battle Ax Creek at Jawbone Flats to form the Little North Santiam River. Opal Lake occupies a cirque, and Opal Creek plunges over a series of three falls for a total drop in elevation of nearly 170 m. The upper falls is less than 0.25 mi northeast of the lake. The outcrops at this stop are bedded pyroclastic rocks that are probably rhyodacitic in composition. On the basis of White's (1980b) lithologic descriptions, similar stratigraphic position, and elevation, it appears that these rocks are part of the Elk Lake formation. The outcrops are well-layered, coarse heterolithic fragmental units of weathered, light-colored units interlayered with dark-colored, fragmental units of uniform clast types. The rocks are cut by a zeolite-coated fracture set that trends N. 40° W. and dips 70° SW. The fracture orientation is a common orientation encountered in the North Santiam mining area. The volcaniclastic rocks are intruded by subvolcanic intrusions that cut the bedding at various angles.

11.6 mi (1.2 mi) White (1980b) mapped the crest of French Creek Ridge as the Elk Lake formation unconformably overlying rocks of the Sardine Formation. The thickness of the Elk Lake formation is 150 m at this locality. White defined two members of the formation: the lower consists of rhyodacitic flows and pyroclastic rocks, the upper of one or more thick flows of hornblende andesite. The pyroclastic units of the lower member are white or pale-pink crystal-lithic tuff; flows are light gray and generally are flow banded. These lavas were probably erupted from a vent complex at the southwestern end of French Creek Ridge. This vent complex is the knob immediately southeast of the road at the crest of French Creek Ridge. White indicates that a small dome can be seen to intrude and to overlie the Sardine lavas at this point. A spine that is 10 m high occurs near the center of the dome. The upper member of the Elk Lake formation overlies the rhyodacitic rocks in the prominent knobs northeast of the pass at Martin Buttes and Byers Peak. These prominences are underlain by a single andesitic flow that is 60 m thick and that displays a prominent colonnade. The andesites contain abundant phenocrysts of plagioclase and less abundant but common phenocrysts of augite. Hypersthene and remnants of probable amphibole crystals are sparsely present as phenocrysts. The Elk Lake formation overlies both the Sardine and Breitenbush Formations with strong angular unconformity. Two K-Ar whole-rock ages for rocks of the Elk Lake formation are 9.8±0.46 m.y. and 11.8±0.4 m.y. (White, 1980b).

13.3 mi (1.7 mi) **Stop 9.** At this switchback, medium- to coarse-grained quartz diorite dikes intrude fine-grained ash beds of the Sardine Formation. Hydrothermal alteration around the dikes has produced zeolitic alteration of the tuffs. Near the contact, the replacement is extensive but decreases in intensity away from the contact where the development of zeolites becomes confined to fracture fillings and breccia cement. Analysis by X-ray diffraction indicates that laumontite is the main zeolite present. The contacts of the dikes are chilled against the wall, and xenoliths of tuff are incorporated into the dike. Abundant fine-grained xenoliths occur in the dike but, except for those near the contacts, are not derived from the immediate wall rocks. The contact strikes N. 10° W. and dips 75° NE. Feldspar phenocrysts are strongly fractured, suggesting shattering such as might occur during hydrofracturing. These intrusions were emplaced at shallow depths.

14.2 mi (0.9 mi) Overview of Sardine Mountain, the type locality of the Sardine series as defined by Thayer (1939). Sardine Mountain is an eroded vent complex. Thin flows, bedded cinders, and radial dikes are considered to be a typical vent-facies assemblage exposed on the northern and western sides of the mountain (White, 1980b). On Hall Ridge immediately south of Sardine Mountain, flows are generally porphyritic, containing abundant plagioclase phenocrysts and lesser amounts of mafic phenocrysts. Most of the andesites have hypersthene and augite as phenocrysts. Lava flows compose from 50 to 70 percent of the formation in areas away from the vent complex. The rest of the formation is composed of lahars and lapilli tuff.

18.4 mi (4.2 mi) Intersection with USFS Road 2223. *Continue straight ahead.* The sharp turn to the right would take you up Sardine Mountain to Tumble Lake.

18.6 mi (0.2 mi) Intersection with Oregon Highway 22. *Turn right to return to Salem or left to go to the towns of Detroit, Breitenbush Hot Springs, or Bend.* □

BOOK REVIEW

by Daniel M. Johnson, Associate Professor of Geography, Geography Department, Portland State University, Portland, Oregon 97207

The Legacy of Ancient Lake Modoc: A Historical Geography of the Klamath Lakes Basin, by Sam and Emily Dicken, published by the authors, available from the University of Oregon Bookstore, 895 E. 13th, Eugene, OR 97403, or Shaw Stationery Company, 792 Main St., Klamath Falls, OR 97601. Price $10.

For nearly 40 years, geographers Sam and Emily Dicken have been exploring and studying their adopted state of Oregon. They have shared the results of these efforts with the public through a series of books and journal articles, beginning with the first edition of *Oregon Geography* published in 1950. In recent years we have been treated to *Two Centuries of Oregon Geography: Vol 1., The Making of Oregon* (1979) and *Vol. 2, A Regional Geography* (1982). Their work on the historical geography of Oregon has now been continued in a newly published book entitled *The Legacy of Ancient Lake Modoc: A Historical Geography of the Klamath Lakes Basin* (copyright 1985 by the authors). This book represents a delightful blend of the two disciplines, but it differs from the Dickens' earlier work in that it focuses on one region of the state, the Klamath Lakes basin of south-central Oregon. It amounts to a chronological description of both natural and human features, beginning with the period of exploration in the early 19th century and continuing to 1985. Throughout, the authors have given careful attention to the perceptions of the region by those who explored and settled it.

In the first chapter, the Dickens present an overview by the interesting technique of escorting the reader on an imaginary airplane flight. Only from this lofty perspective can the unity of the Klamath Lakes region be appreciated. As they point out, the "unifying feature is the lake plain, the bed of Old Lake Modoc," a Pleistocene lake whose shoreline was drawn for the first time by Sam Dicken in an article in the November 1980 issue of *Oregon Geology*. Modern lakes of the region, including Oregon's largest (Upper Klamath Lake), are remnants of this larger Lake Modoc. *(Continued on page 10, **Book Review**)*

ABSTRACTS

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 OF THE GREEN MOUNTAIN-YOUNGS RIVER AREA, CLATSOP COUNTY, NORTHWEST OREGON, by Carolyn Pugh Peterson (M.S., Oregon State University, 1984 [thesis compl. 1983])

The upper Eocene to lower Oligocene Oswald West mudstone is the oldest formation (informal) in the Green Mountain-Young's River area. This 1,663-m-thick hemipelagic sequence was deposited in a low-energy lower to upper slope environment in the Coast Range forearc basin. The formation ranges from the late Narizian to the early Zemorrian (?) in age and consists of thick-bedded bioturbated foraminiferal claystone and tuffaceous siltstone. Rare glauconitic sandstone beds also occur. In the eastern part of the study area, the upper part of the Oswald West mudstone is interbedded with the upper Refugian Klaskanine siltstone tongue. This informal unit consists of thick bioturbated sandy siltstone and silty sandstone that is a lateral deep-marine correlative of the deltaic to shallow-marine Pittsburg Bluff Formation in the northeastern Coast Range.

Discontinuous underthrusting of the Juan de Fuca oceanic plate at the base of the continental slope of the North American plate caused extensive uplift and subsidence along the Oregon continental margin throughout the Cenozoic (Snavely and others, 1980). Initiation of Oregon Coast Range uplift and accompanying erosion in the early Miocene, coupled with a global low stand of sea level (Vail and Mitchum, 1979), stripped most of the Oligocene (Zemorrian) Oswald West strata and in places much of the uppermost Eocene (upper Refugian) Oswald West strata in the field area, creating an unconformity. Deformation accompanying uplift included a system of east-west-trending, oblique-slip faults.

The Pillarian to Newportian-age Astoria Formation unconformably overlies the Oswald West mudstone and reflects deposition offshore from an open, storm-dominated coast during an early to middle Miocene transgression. Deposition of the Big Creek sandstone and Silver Point mudstone members of the Astoria Formation was controlled in part by submarine paleotopography that developed as a result of early Miocene deformation of the Oswald West strata. The up-to-200-m-thick Big Creek member varies from storm-deposited laminated sandstone to bioturbated mollusk-bearing silty sandstone that accumulated during fair-weather conditions on the inner to middle shelf. Overlying and perhaps in part laterally equivalent to the Big Creek member is the up-to-200-m-thick, deeper marine Silver Point member which consists of two lithologies: (1) interbedded, micaceous, turbidite sandstones and laminated mudstone; and (2) laminated bathyal mudstone that intertongues with and caps the turbidite sequences. The turbidite lithology is composed of two facies: (1) an underlying sand-rich facies, transitional between the shallow-marine Big Creek member and bathyal Silver Point strata, that was deposited on the outer shelf by storm-induced turbidity currents; and (2) an overlying sand-poor facies that was deposited at bathyal depths. The turbidite facies channelized and at some places removed the underlying Big Creek member and was deposited directly over Oswald West mudstone. The Astoria depositional sequence ranges from inner to outer neritic to bathyal facies and reflects continued deepening and anoxic depositional conditions of the Astoria basin through the middle Miocene. Big Creek and Silver Point sandstone petrology reflects volcanic sources from an ancestral western Cascades volcanic arc and metamorphic and granitic basement rocks farther east via an ancestral Columbia River drainage system. Diagenetic effects include: (a) formation of local calcite concretionary cements; and (b) formation of pore-filling smectite from alteration of volcanic rock fragments.

At least six middle Miocene Columbia River Basalt Group intrusive episodes affected the Green Mountain-Youngs River area soon after deposition of the Astoria Formation. These basalt sills and dikes include normally polarized and reversely polarized low MgO-high TiO_2, low MgO-low TiO_2, and high MgO Grande Ronde basalt chemical subtypes and two porphyritic Frenchman Springs Member basalts (Ginkgo and Kelly Hollow(?) petrologic types). These basalt intrusions are virtually indistinguishable, based on chemistry, from subaerial flows of the plateau-derived Columbia River Basalt Group subtypes at nearby Nicolai Mountain and Porter Ridge. This correlation supports the Beeson and others (1979) hypothesis that the intrusions are not of local origin but formed by the invasion of the flows into the Miocene shoreline sediments to form "invasive" sills and dikes. Many dikes were emplaced along northeast- and northwest-trending faults, and some (*i.e.*, Ginkgo) cut older sills (Grande Ronde). A laterally extensive Frenchman Springs sill occurs under an older widespread Grande Ronde sill. From this older over younger intrusive relationship, a mechanism of "invasion" of sediment from overlying lava flows is difficult to envision.

A pulse of rapid subduction starting in the middle Miocene (Snavely and others, 1980) was accompanied by renewed uplift, intensive block faulting, and continued development of the earlier formed Coast Range uplift. Left-oblique northeast-trending faults and conjugate northwest-trending right-oblique faults offset Grande Ronde and Frenchman Springs dikes and sills. This conjugate fault pattern may reflect oblique east-west convergence between the North American and Juan de Fuca plates.

The Silver Point mudstones and Oswald West mudstones have high total organic carbon contents, up to 5.5 percent, but are thermally immature and may act only as a source for biogenic gas(?) in the subsurface. Suitable reservoir rocks, such as the gas-producing upper Eocene Cowlitz Formation Clark and Wilson sandstone, may pinch out before reaching the Green Mountain-Youngs River area and are yet to be penetrated by exploration drilling. Post-middle Miocene fault traps abound in the area, although these faults might also breach subsurface natural gas reservoirs in the Green Mountain-Youngs River area.

LANDSLIDE HAZARDS IN THE DALLES, WASCO COUNTY, OREGON, by Michael Hugh Sholin (M.S., Oregon State University, 1982)

Human activity has led to the reactivation of portions of a Pleistocene landslide complex in The Dalles, Oregon. Slope movements are in rocks of the Chenoweth Formation: agglomerate, conglomerate, tuff breccia, sandstone, and siltstone. Slope movements occur in at least two distinct areas in The Dalles. At one, the shear surface is defined by the contact between the Chenoweth Formation and the underlying Columbia River basalt. Data from inclinometer readings at the other area fail to reveal a well-defined shear surface. Slope movements in The Dalles cause tens of thousands of dollars worth of damage annually and may present a threat to human safety. So far, there has been little organized response to this hazard. □

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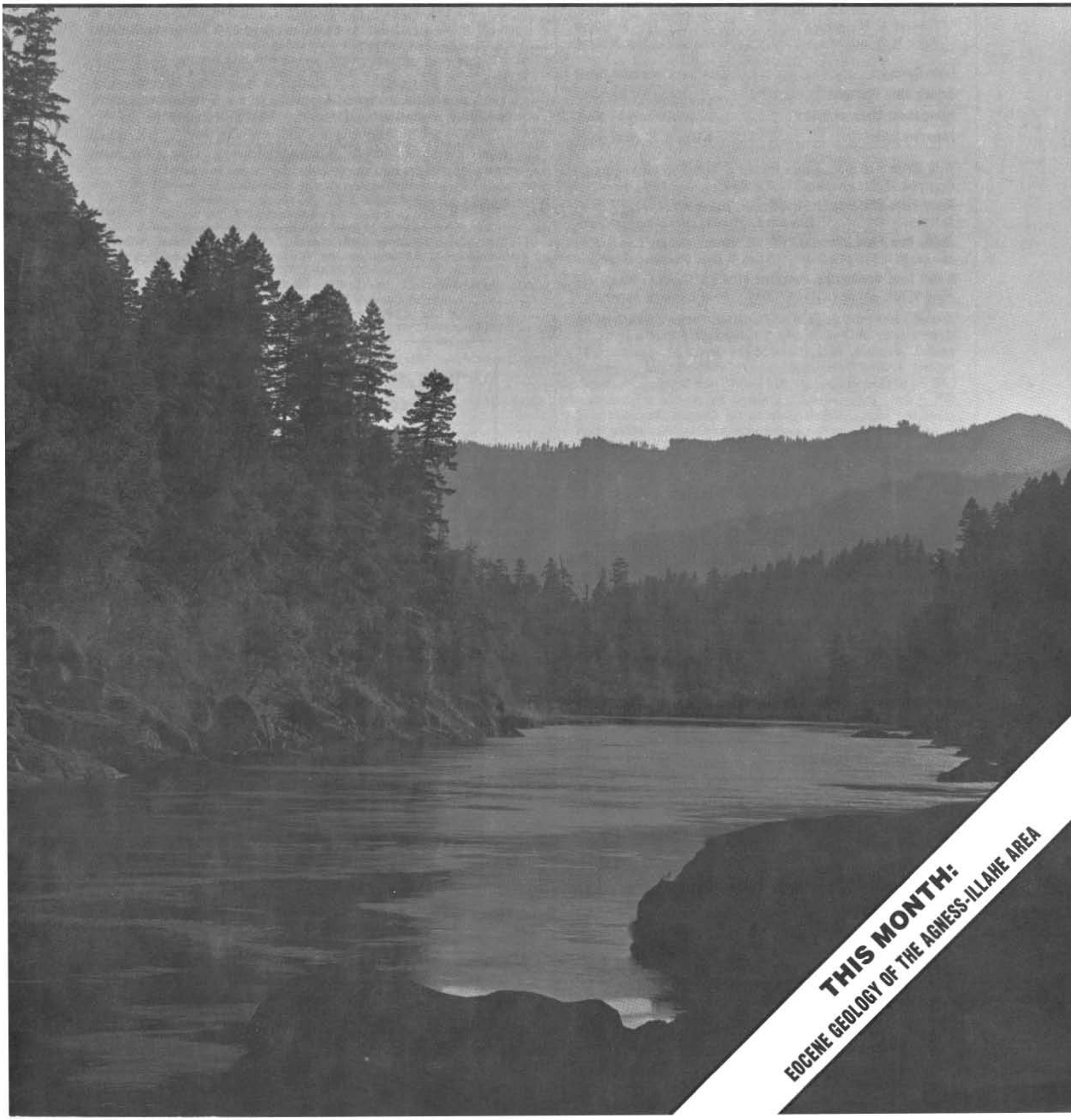

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COVER PHOTO

Typical topography along the Rogue River near Illahe. Article beginning on next page describes the Eocene geology of this area. Photo courtesy Michael S. Miller, U.S. Bureau of Mines, Spokane, Washington.

OIL AND GAS NEWS

Columbia County — Mist Gas Field

ARCO Crown Zellerbach 23-15, located in SW¼ sec. 15, T. 5 N., R. 4 W., was drilled to a total depth of 2,770 ft and completed to production on December 10, 1985. This is an offset to the ARCO Crown Zellerbach 31-16, originally drilled and completed by Reichhold Energy. Neither well is on line yet.

ARCO Longview Fibre 23-25, located in SW¼ sec. 25, T. 6 N., R. 5 W., was drilled to a total depth of 1,979 ft and completed on December 15, 1985.

ARCO Columbia County 23-22, located in SW¼ sec. 22, T. 6 N., R. 5 W., near three producers, was spudded December 10, 1985, and drilled to a total depth of 2,028 ft. This well was also a producer, completed on December 20. This brought the number of ARCO successes during the year to eight, seven of which had been originally filed by Reichhold Energy. This is the most completions yet in a single calendar year.

Recent permits

Permit no.	Operator, well API number	Location	Status, proposed total depth (ft)
344	ARCO Columbia County 41-2-1 009-00185	NE¼ sec. 2 T. 5 N., R. 5 W. Columbia County	Application; 2,000.

□

AIME member receives national award

Harry Czyzewski, P.E., President of Oregon Technical Services Center, Inc., Portland, and a life member of the American Institute of Mining Engineers (AIME), has been named to receive the Roger W. Truesdail Award for Outstanding Service to Independent Laboratories from the American Council of Independent Laboratories (ACIL).

Czyzewski has had a long and distinguished career within ACIL and in the broader consulting engineering/testing community. He is a past president of ACIL, served on its board for six years, and headed its Tax-Favored Competition

*(Continued on page 22, **Czyzewski**)*

Eocene geology of the Agness-Illahe area, southwest Oregon

by Raisuddin Ahmad, Department of Geology, University of Oregon, Eugene, Oregon 97403*

INTRODUCTION

The Agness-Illahe area (Figure 1) straddles the Mesozoic-Cenozoic boundary in southwestern Oregon. Published regional geologic maps that include the Agness-Illahe area are those of Wells and Peck (1961), Dott (1971), and Baldwin (1974). Baldwin (1974) describes and differentiates the early Tertiary formations of southwestern Oregon; however, the Agness-Illahe area has not been mapped in local detail. The Rogue River cuts through the Tertiary and pre-Tertiary rocks in the area (Figure 2), creating excellent outcrops that make up a continuous section thousands of meters thick. These outcrops have received very limited attention by the previous workers, except for some paleontological investigations by Thoms (1975) and Miles (1977).

The present study was initiated to prepare a geologic map of the area and to study the stratigraphy, structure, lithology, and petrography of exposed rock units. The purpose of the study was to reconstruct the Eocene geologic history of the area.

Field work for this study was conducted during the summers of 1978 and 1979. Much of the measurement of the stratigraphic section was done along the Rogue River canyon, but part of the section was also measured along roadcuts and in outcrops on top of the mountains. In areas lacking continuous outcrops, thickness of stratigraphic section was approximated.

REGIONAL GEOLOGICAL SETTING

The area under investigation is located within the Agness quadrangle, southwest Oregon (Figure 1). It covers about 91 km^2 (35 mi^2). Within the area, Tertiary rocks of the Coast Range are tectonically juxtaposed with pre-Tertiary rocks of the Klamath Mountains to the south, southeast, and southwest. Farther to the east lie the Cenozoic, chiefly andesitic volcanic rocks of the Cascade volcanic arc. The Klamath Mountains consist of tectonically stacked sedimentary and metasedimentary rocks that were intruded by dioritic and ultramafic igneous bodies (Dott, 1965). The Oregon Coast Range consists of Cenozoic sedimentary rocks with thick submarine pillow basalts and other basic intrusive bodies (Snavely and Wagner, 1963; Snavely and others, 1969; Baldwin, 1974, 1975).

The region has been affected by intense tectonic activity. Pre-Tertiary rocks of the Klamath Mountains are very intensely folded and faulted. Thrust faulting is a common structural phenomenon in both the pre-Tertiary and lower Tertiary rocks in the region (Baldwin, 1974, 1975). The intensity of folding in the Klamath Mountains is greater than in the Oregon Coast Range. Folds in the Klamath Mountains trend mainly northwest-southeast, whereas those in the Coast Range have dominantly north-south and northeast-southwest trends.

STRATIGRAPHY

The major part of the Agness-Illahe area is underlain by Tertiary rocks, and the present study deals with the Eocene formations of the area. Pre-Tertiary rocks include sedimentary rocks of the Myrtle Group (Baldwin, 1974) in the western part of the area and small intrusive bodies of serpentinite; however, these rocks are not discussed in this report. Baldwin (1974) elevated the Eocene Umpqua Formation of Diller (1898) to group status and subdivided it into the Roseburg, Lookingglass, and Flournoy Formations (Figure 3). Baldwin (1974) further subdivided the Lookingglass Formation into the Bushnell Rock, Tenmile, and Olalla Creek Members and the Flournoy Formation into the White Tail Ridge and Camas Valley Members. Contacts between the members are gradational in places.

Roseburg Formation

The Roseburg Formation is partially exposed along the Rogue River canyon near the Rogue River bridge between Waters Creek and Slide Creek, where it is in fault-bounded contact with the pre-Tertiary Myrtle Group sediments to the south-southwest (Figure 3). The zone of contact between the Roseburg Formation and the overlying Bushnell Rock Member of the Lookingglass Formation (Figure 4) is poorly exposed; however, the massive-bedded conglomerates of the lower Bushnell Rock Member distinguish it from the upper part of the Roseburg Formation. The zone of contact was mapped near Twomile Creek (Figure 3).

The thickness of Roseburg Formation strata exposed in the Agness-Illahe area is about 130 m (426 ft). These strata are made up of sandstones and siltstones and appear to represent the upper(?) part of the formation. Baldwin (1975) indicated that the Roseburg Formation is about 3,000-4,000 m (9,800-13,000 ft) thick at its type section at Glide. Faulting of this formation against the pre-Tertiary units in the Agness-Illahe area probably cut out its lower part.

Within the study area, the Roseburg Formation consists of a turbidite sequence of three distinct types of rocks: pebbly sandstone, sandstone, and siltstone. The sandstones are hard, compact subfeldspathic lithic wackes containing angular to subrounded quartz; plagioclase; potassium feldspars; heavy minerals; and igneous, metamorphic, and sedimentary rock fragments. Calcite, chert, and hematite are the principal types of cements. Detailed petrographic description is given in Ahmad (1981).

Miles (1977) studied planktonic Foraminifera and calcareous nannofossil assemblages of the formation in the Agness-Illahe area and assigned them to zone P7/8 of the standard tropical zonations. Miles indicated that the Foraminifera may in part be stratigraphically as low as zone P6b, which is late Paleocene in age. Thoms (1975) examined the benthic Foraminifera of the lower Umpqua Formation (Roseburg Formation of Baldwin, 1974) and assigned them to the Penutian Stage. On the basis of the age determination of Miles (1977) and the stratigraphic position below the pre-Lookingglass unconformity, Roseburg Formation rocks of the area can be tentatively correlated with the upper part of the formation in the type area near Glide (Baldwin, 1975) as well as in other northern sections (Ahmad, 1981, 1982).

No significant paleocurrent information was found during the present investigation. Snavely and Wagner (1963) determined that during early Eocene time, the paleocurrent direction in the area was northward. Ahmad (1981) suggested that sediments of the Roseburg Formation in the Agness-Illahe area were derived mostly from a terrain much like the present Klamath Mountains to the south (Figure 5A) and were probably transported by high-gradient streams in a subtropical climate (Miles, 1977).

During the early Tertiary period, a forearc basin was in existence in western Oregon on the trench slope along the active subduction zone where the Farallon Plate was being subducted beneath the North American Plate (Dickinson, 1976). This forearc basin is the north-trending eugeosynclinal basin of

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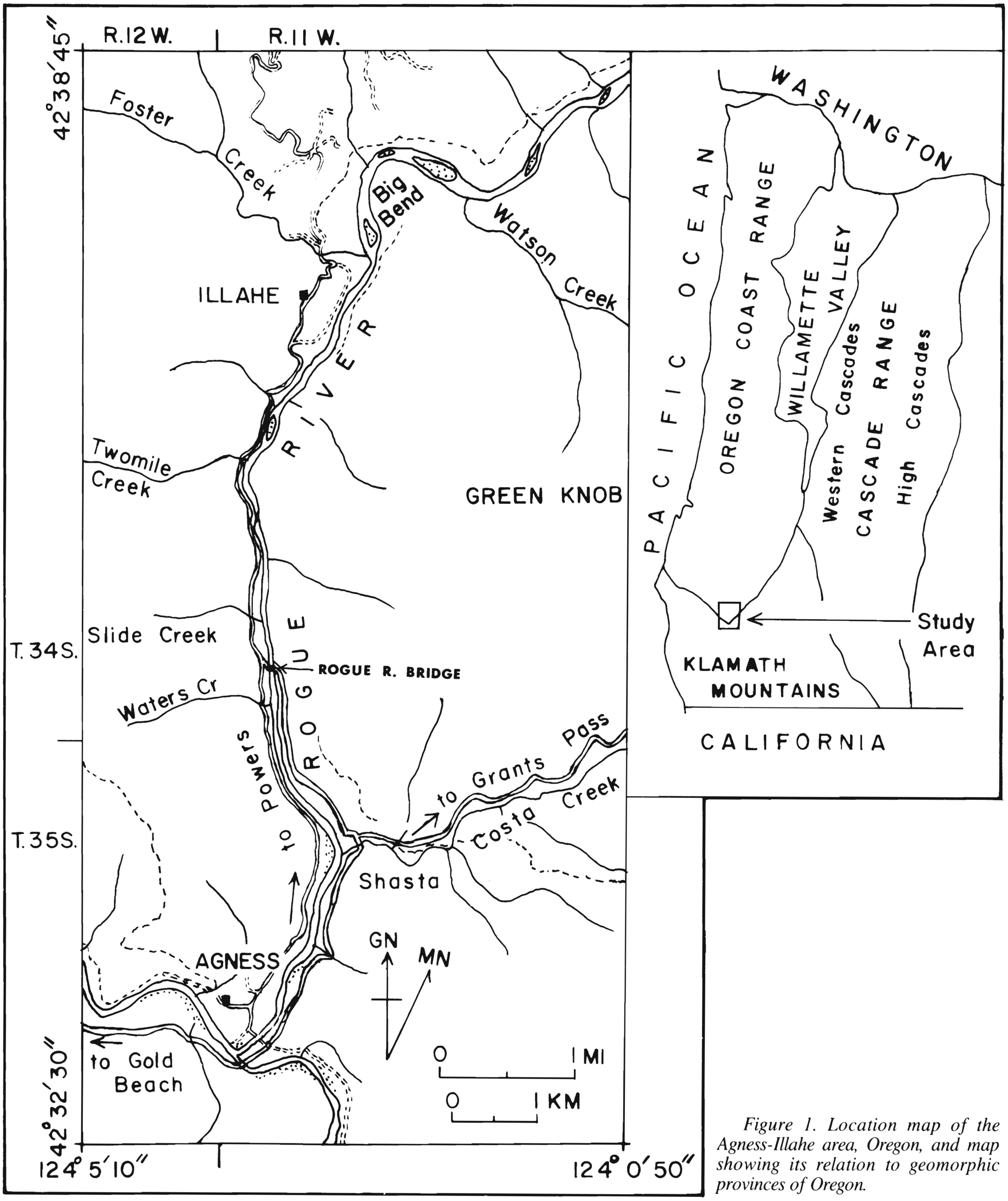

Figure 1. Location map of the Agness-Illahe area, Oregon, and map showing its relation to geomorphic provinces of Oregon.

Snavely and Wagner (1963). Turbidite sandstones of the Roseburg Formation are believed to have been deposited in this forearc basin (Figure 5A). A detailed discussion on the depositional environment of this formation is available in Ahmad (1981).

Lookingglass Formation

The Lookingglass Formation in the Agness-Illahe area is in unconformable contact with the underlying Roseburg Formation. This unconformity is a striking break in the Coast Range Tertiary record (Baldwin, 1974, 1975). In the Agness-Illahe area, the Lookingglass Formation is represented by the Bushnell Rock

Member and the Tenmile Member. The Olalla Creek Member is missing (Figure 4), because either it was not deposited in this area or it was eroded away before deposition of the Flournoy sediments (Ahmad, 1982).

Bushnell Rock Member: This member attains a thickness of about 735 m (2,411 ft) in the Agness-Illahe area. It has a basal sequence of petromict conglomerates followed stratigraphically by approximately 665 m (2,182 ft) of turbidite sandstones and siltstones (Figure 4). The conglomerate sequence is about 70 m (230 ft) thick and is composed of two distinct units: a basal unit of massive-bedded, moderately to poorly sorted conglomerate and an upper unit containing relatively thinner bedded, normally graded, well-sorted conglomerates (Ahmad, 1981).

Fossils are rare in Bushnell Rock conglomerate within the study area. A few boulders of conglomerate, contain fossils of the pelecypod *Buchia* (Cretaceous) that were probably derived from the pre-Tertiary formations. The molluscs *Venericardia aragonia, Tellina, Turritella, Amaurellina,* and oyster fragments are the most frequently found fossils (Haq, 1975).

Based on clast composition, fossil content of some conglomeratic boulders, and structural and textural criteria, this author (Ahmad, 1981) suggested that conglomerates of the Bushnell Rock Member were derived from the Klamath Mountains to the south and were deposited in a fluvio-neritic environment (Figure 5B). The relatively thinner bedded, normally graded, well-sorted, clast-supported conglomerates of the upper unit are believed to be resedimented conglomerates formed by turbidity currents.

Conglomerates of the Bushnell Rock Member are overlain by turbidite units consisting of sandstone, siltstone, and pelagic shale. These rocks are very well exposed along the Agness-Illahe Road as well as in the Rogue River canyon near the mouth of Twomile Creek. The sandstones are gray, hard, moderately compact, coarse- to medium-grained, and moderately to poorly sorted feldspathic to subfeldspathic lithic wackes. They contain quartz, chert, plagioclase feldspars (Ab_{60}-Ab_{85}), potassium feldspars, rock fragments excluding chert, serpentine and nonmatrix chlorite, heavy minerals, and clay matrix (Ahmad, 1981).

A few organic constituents such as echinoderm fragments, fragments of Foraminifera, and indurated fragments of spumellarian Radiolaria were found in these sandstones. These microfossils were identified by William N. Orr (personal communication, 1981). A middle Eocene crab (Kooser and Orr, 1973), echinoderms, gastropods, and pelecypods are also present in these sandstones. All of these megafossils are of early to middle Eocene age. The outcrop from which these fossils were collected lies about 1 km (0.6 mi) southeast of the mouth of Shasta Costa Creek and is accessible by a trail (Figure 3).

After comparing the petrographic characteristics of these sandstones with selected sandstone suites of known provenances, this author (Ahmad, 1981) suggested that Lookingglass sandstones in the study area were derived mostly from the Klamath Mountain terrane to the south (Figure 5B). Lithology, sedimentary structure, and the presence of shallow-marine faunas suggest that sandstones of the Bushnell Rock Member in the Agness-Illahe area were deposited in a shallow forearc basin (Ahmad, 1981, Figures 36-37). Reconstruction of the paleogeography at the time of formation of the Bushnell Rock Member is shown in Figure 5B.

Tenmile Member: The Tenmile Member is made up of about 240 m (787 ft) of turbidite sandstone and siltstone (Figure 4). These rocks are very well exposed along the Rogue River canyon near Illahe and Foster Bar. Each turbidite unit generally contains beds of gray, moderately compact, medium- to fine-grained, normally graded lithic sandstone and siltstone. Calcite and chert

Figure 2. Rogue River canyon carved into the Eocene strata offers excellent outcrops that are continuous for several kilometers in the Agness-Illahe area.

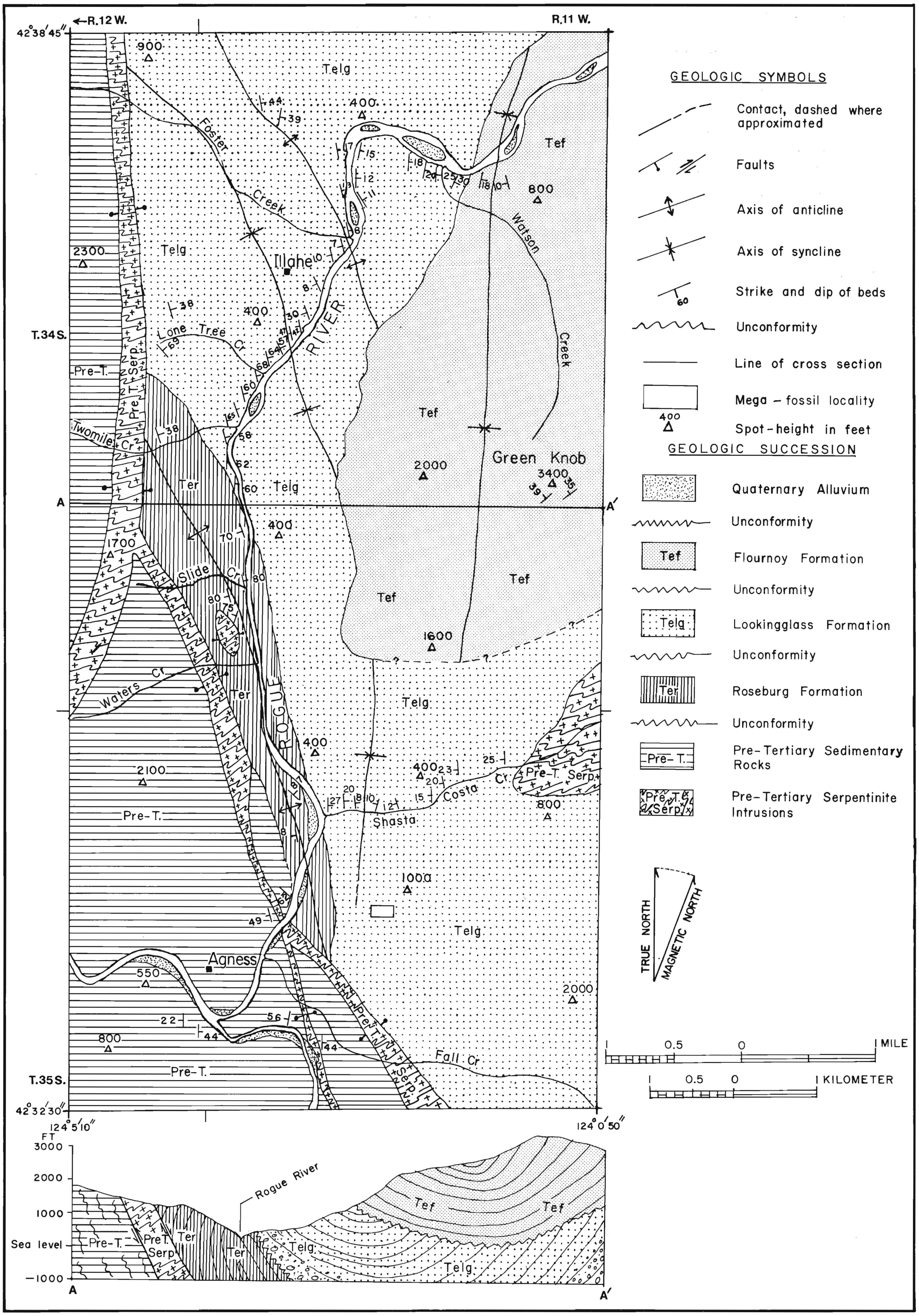

Figure 3. Geologic map of the Agness-Illahe area.

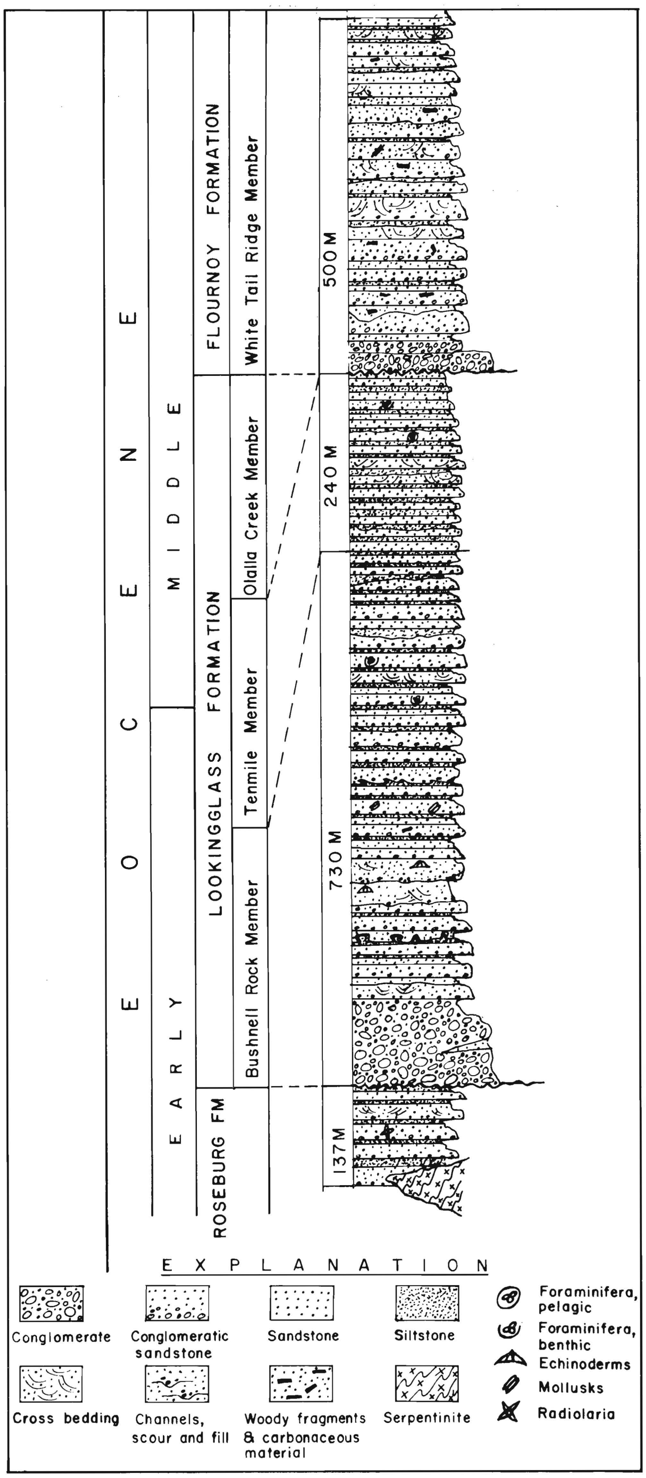

Figure 4. Measured stratigraphic column of the rocks of early to middle Eocene age in the Agness-Illahe area, Oregon.

are the main cementing agents. Micro cross-laminations are present in the upper part of some fine sandstone beds. Small-scale scour-and-fill structures are present in some of the beds of siltstones.

Some microfaunas found in the Tenmile Member are similar to those of the Bushnell Rock Member sandstones. Based on the textural and mineralogical criteria, the Tenmile Member sandstones appear to have been derived mainly from the Klamath Mountains to the south. Bed geometry, sedimentary structures, and presence of shallow-water megafossils and microfossils suggest that the sandstones were deposited by turbidity currents in a forearc basin. Figure 5C shows a paleogeographic reconstruction of the area during deposition of the Tenmile Member sediments.

Flournoy Formation

The Flournoy Formation crops out in a considerable part of the study area (Figure 3) and attains a thickness of about 500 m (1,640 ft) (Figure 4). The southern extent of the formation is not well exposed. The base of the formation is marked by a 50-m (164-ft)-thick sequence of brown, graded sandstone. These conglomerates and sandstones are well exposed near the mouth of Watson Creek. Because of structural and lithologic similarities, the Flournoy Formation rocks of the study area are believed to represent the White Tail Ridge Member exposed in its type area in the Flournoy Valley and described by Baldwin (1974, 1975).

White Tail Ridge Member: The conglomerates at the basal part of this member are massive bedded and clast supported with a matrix consisting of sand- and silt-size materials. The clast size ranges from about 15 cm (6 in.) to 2 cm (0.8 in.), with an average size of about 5 cm (2 in.). The average clast size gradually decreases stratigraphically upward. The clasts are rounded to subangular and are made up of fragments of basalt, diorite, andesite, dacite, rhyolite, sandstone, conglomerate, limestone, chert, greenstone, schist, and metasedimentary rocks including quartzite.

These conglomerates closely resemble those of the lower unit of the Bushnell Rock Member except for smaller clast size of the latter. Conglomerates of the White Tail Ridge Member were probably deposited in a shallow-marine environment (Baldwin, 1974), but the basal part exposed near Watson Creek is probably fluvial, as suggested by the absence of faunas.

In the study area, sandstones of the White Tail Ridge Member attain a thickness of about 450 m (1,480 ft). These sandstones are light-brown to light-gray, moderately hard, coarse- to medium-grained, normally graded, and moderately to poorly sorted subfeldspathic lithic wackes. They contain mainly quartz, feldspar, lithic fragments, and variable amounts of matrix materials. Mica flakes and small fragments of plant debris are present along the bedding planes and dispersed within sandstone beds. Calcite, clay minerals, chert, and ferruginous materials are the main cementing materials. Extensive replacement of matrix materials by calcite is conspicuous. Some of the sandstone beds have cross-laminations and scour-and-fill structures.

Thoms (1975) assigned the microfossils of the Flournoy Formation to the Ulatisian Stage. Based on the study of planktonic foraminiferal assemblages, Miles (1977) indicated that sediments of the Flournoy Formation were deposited during middle Eocene time and assigned them to zone P7/8.

Bed thickness (about 1 m [3.3 ft]), presence of shallow-water planktonic and benthic Foraminifera (Miles, 1977), presence of small fragments of wood, and normal grading of the sandstones suggest that the sandstones at the basal part of the White Tail Ridge Member were deposited in a shallow-marine shelf environment or in the upper trench slope by turbidity currents. With continued transgression of the sea, the upper, thinner bedded sandstones were probably deposited in a deeper water environment on the upper trench slope or on the lower trench slope. A paleogeographic reconstruction of the area at the time of deposition of the White Tail Ridge Member sediments is shown in Figure 5D.

STRUCTURAL GEOLOGY

The geological structure of the Agness-Illahe area is complicated. Two anticlines, two synclines, and three major faults have

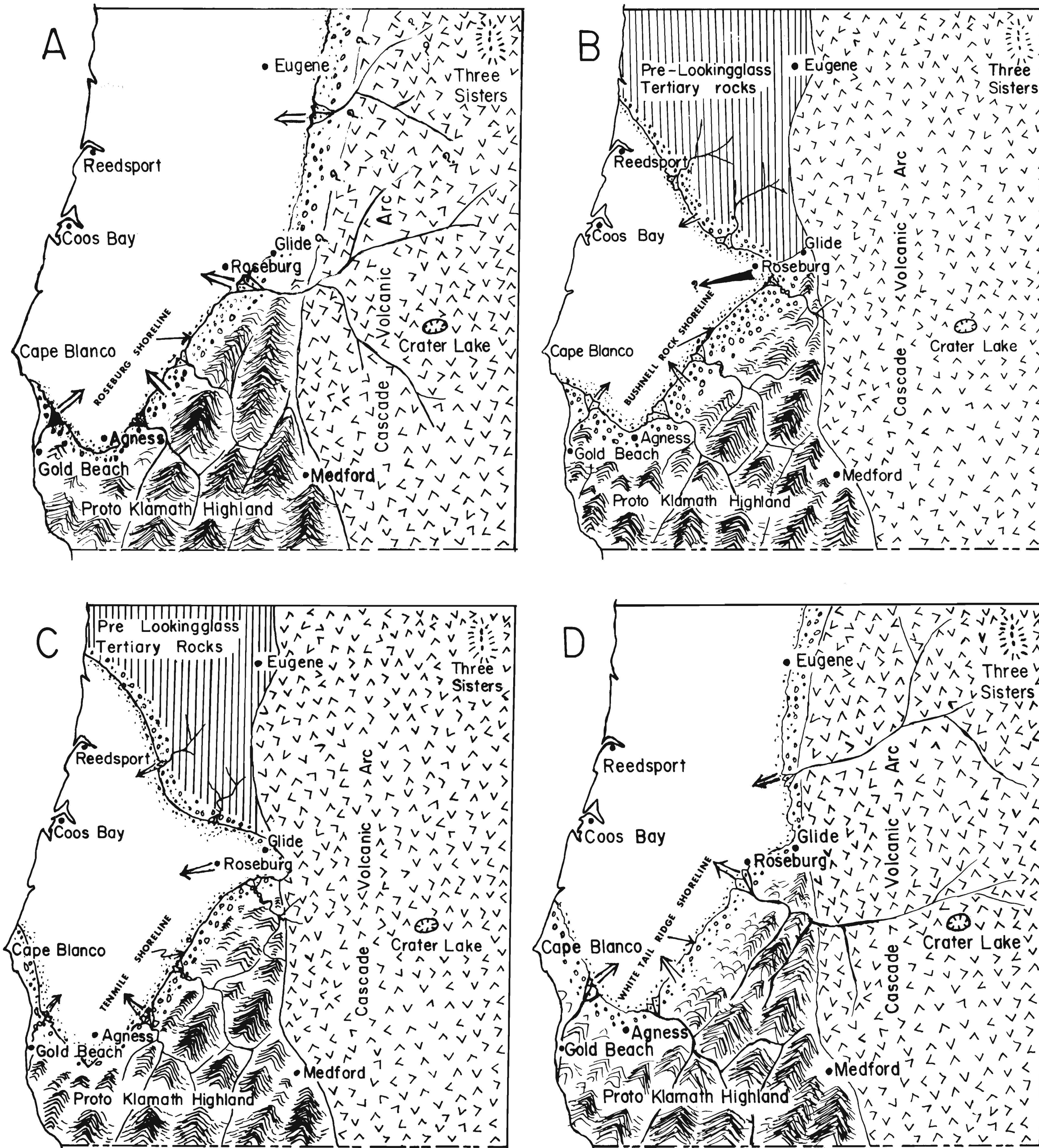

Figure 5. Paleogeographic maps of southwest Oregon at different times during the early to middle Eocene: A = during deposition of the upper Roseburg strata; B = during deposition of the Bushnell Rock Member of the Lookingglass Formation; C = during deposition of the Tenmile Member of the Lookingglass Formation; D = during deposition of the White Tail Ridge Member of the Flournoy Formation.

been mapped (Figure 3). Four major episodes of deformation can be recognized: (1) deformation of the pre-Tertiary Myrtle Group sedimentary strata prior to the deposition of sediments of the Roseburg and younger formations, (2) deformation and uplift of the Roseburg Formation prior to deposition of sediments of the Lookingglass Formation, (3) deformation and uplift of the Lookingglass Formation and the previously deformed Roseburg and pre-Tertiary strata, and (4) post-Flournoy deformation affecting the Flournoy and other older rocks of the area.

Strata of the Roseburg, Lookingglass, and Flournoy Formations are folded into several anticlines and synclines (Figure 3). These folds are asymmetric and generally trend north-northwest; however, the axial trends appear to be more northerly in the younger formations. Strata on the southwestern flanks of these folds are more steeply dipping relative to those on the northeastern flanks. Some of the folds are localized only within the strata of a single formation. Plots of the poles of bedding planes on a Schmidt equal-area net tend to cluster around different points for different formations, suggesting separate episodes of tectonic activity responsible for their deformation (Ahmad, 1981). The general trend of the anticlinal fold axis in the Roseburg Formation within the map area is approximately N. 10° W., which is a deviation from the regional northeast-southwest trend of the folds of the same formation in the Oregon Coast Range (Baldwin, 1974).

Several prominent faults were mapped (Figure 3). All of the major faults appear to be normal/reverse faults along which the rocks of Roseburg and Lookingglass Formations were downdropped against the pre-Tertiary rocks of the Myrtle Group. Displacements along the faults could not be determined. Large masses of serpentinite occur along the fault zone. In addition to the faults mapped, several minor east-west-trending transverse faults that extend for distances of only a few tens of meters occur in the map area.

Joints are very common in rocks of the Roseburg and Lookingglass Formations. Most of the joints are rectilinear, but a few of them have corners that are somewhat rounded and have nearly polygonal shapes that resemble mud cracks. The oblique joints are most common in the upper part of the Tenmile Member. At some places the joints are limited to individual strata, but in most localities they extend across several strata. Length of individual less joints varies from than a meter to several meters.

CONCLUSIONS

(1) The Roseburg and Lookingglass Formations within the Agness-Illahe area have fault-bounded contacts with the pre-Tertiary rocks of the Klamath Mountains. (2) Strata of the Roseburg Formation exposed in this area consist essentially of turbidite sandstones deposited in a gradually subsiding forearc basin during late Paleocene to early Eocene time. (3) The Bushnell Rock Member unconformably overlies the Roseburg Formation. Its basal massive-bedded conglomerates are believed to have been deposited in fluvio-neritic environments; the upper, normally graded, and relatively thinner bedded conglomerates and turbidite sandstones were deposited in continental-shelf to -slope environments along the forearc basin. Subsidence of the basin continued while the turbidite sandstones of the Tenmile Member were deposited in the forearc basin. The Olalla Creek Member is missing in the study area, perhaps because of nondeposition or erosion of the member due to tectonic uplift above base level prior to deposition of the Flournoy Formation. Deposition of the Lookingglass sediments took place during early Eocene to early middle Miocene time. (4) Conglomerates of the White Tail Ridge Member unconformably overlie the Olalla Creek Member of the Lookingglass Formation in the study area and, except for the probably nonmarine rocks near the mouth of Watson Creek, are tentatively interpreted to have been deposited in a shallow-marine environment. However, further study is needed for a better environmental interpretation of these conglomerates. The overlying turbidite sandstones of the member are believed to have been deposited in a forearc basin during middle Eocene time. (5) The intensity of folding of the Roseburg, Lookingglass, and Flournoy Formation strata decreases gradually upward in the stratigraphic section, reflecting a gradual decrease in the intensity of tectonic activity in the area since early Eocene time. (6) The Roseburg and Lookingglass strata were intruded by large masses of serpentinite.

ACKNOWLEDGEMENTS

Most of the contents of this paper are from the author's master's thesis (Ahmad, 1981) that was completed at the Geology Department, University of Oregon. I express my special thanks to E. M. Baldwin, who introduced me to the Agness-Illahe area, helped during the field work, critically reviewed the manuscript, and made valuable comments and suggestions. I thank Sam Boggs, Jr., who generously supervised the project, critically reviewed the manuscript, and made valuable comments and suggestions. Some financial support for the field work and preparation of maps and thin sections was provided from the Student Research Fund of the Geology Department, University of Oregon.

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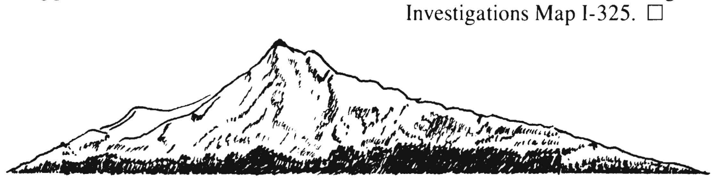

BLM shares income, forecasts mineral-resource activity

Oregon gains cash from BLM

Oregon and its counties received $511,188.28 from the U.S. Bureau of Land Management (BLM) as their share of 1985 income from public lands. The total includes $186,784.61 from grazing income and $324,403.67 from sale of minerals, timber, and land. Nationwide, BLM distributed a total of $3,306,989.62 from these sources to counties and states.

Not included in the above is income from BLM's management of the so-called O&C lands. These are lands that were once given to the Oregon and California Railroad Company to subsidize railroad construction but were taken back by the Federal government when the company failed to live up to the agreement. From this source, Oregon counties in which O&C timberlands are located received a total of $61,123,527.98 for fiscal year 1985.

States and counties receive half of the income from mineral leases and patents, a share varying from 12.5 to 50 percent of grazing fees and leases, and 4 percent of the income from land and materials sales. Counties in which O&C timberlands are located receive 75 percent of the income but voluntarily return 25 percent to the Federal treasury for investments in O&C land management.

Mineral-resource plans revealed

A five-year forecast of mineral-resource development is now available for the first time concerning BLM activities in Oregon and Washington. The 56-page report describes important Pacific Northwest minerals, their present status, and BLM forecasts for the agency's five-year plans. BLM manages mineral and energy resources on approximately 53 million acres of public lands and is minerals trustee for more than 3 million acres of Native American lands in Oregon and Washington.

Patrick Geehan, BLM deputy state director for mineral resources, expects an increase, by 1990, of approximately 15 percent in agency work devoted to mineral resources, mostly in oil-and-gas, geothermal, and hard-rock-mining programs. The anticipation of more activity in these fields is reflected in specific forecasts in the report:

There will be at least one new oil or natural gas commercial discovery in BLM's Spokane or Salem districts by 1990.

There will be no unusual new demand for geothermal leasing, but emphasis will shift from leasing to exploration, probably on the flanks of the Cascades.

Coal exploration will continue west of the Cascades.

Gold prices will rise and thus lead to consequent rising activity in mining claims.

Demand for sand and gravel and for non-energy leasable minerals such as potassium, sodium, and phosphates will remain about the same, while the market for uranium is depressed now and will likely remain so for some time.

Geehan said that the agency welcomes comments from the public both on description of mineral terrains and interpretation of future BLM needs.

— *Compiled from BLM news releases*

Fireballs sighted

The following fireballs were seen in the skies over Oregon and reported to Dick Pugh in the recent months:

November 4, 1985, observation by Erica Nissel at 7:55 p.m. PST in the Portland area, Multnomah County, where there were many city lights. The fireball was first seen 5° east of north at an altitude of 45° and last seen 5° west of north at an altitude of 35°. The duration of the event was 3 seconds. The extremely bright, silver-white, oval fireball was half the size of the full moon and had a silver-white tail that covered the full length of the path. The observer heard a whistling sound during the last third of the event.

November 13, 1985, observation by Gordon Bolton at 10:14 p.m. PST, 2 km north of Forest Grove, Washington County. The fireball was first seen 30° east of south at an altitude of 40° and last seen 60° east of south at an altitude of 10°. The duration of the flight was 3 seconds. The yellow-white fireball, which was four times the diameter of Venus, had a short yellow tail. No sound was heard, no breakup was observed, and the fireball did not cast a shadow.

These sightings have been reported to the Scientific Event Alert Network, Smithsonian Institution. Anyone with any additional information about these or other fireball sightings should contact Dick Pugh, Cleveland High School, 3400 SE 26th Avenue, Portland, OR 97202, phone (503) 233-6441. □

North Santiam mining area — additional information

We are supplying here some information that should have been part of the article and field trip guide on the North Santiam mining area published in the December 1985 and January 1986 issues of Oregon Geology:

ACKNOWLEDGMENTS

The authors gratefully acknowledge the cooperation and support of Shiny Rock Mining Company and its president, George Atiyeh, who made this project possible. The discussion and road log were abstracted from a paper prepared for the Penrose Conference titled "Geochemistry of the Environment Near a High-Level Nuclear-Waste Repository" that was held at Rippling River Resort near Mount Hood, September 9-14, 1984. George Priest reviewed an early draft of this manuscript.

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***(Czyzewski,** continued from page 14)*

Committee. He has received "Distinguished Service" awards from the Oregon and national divisions of the American Consulting Engineers Council and the National Council of State Boards of Engineering Examiners. He was given several national Engineering Excellence awards and, in 1972, was named "Professional Engineer of the Year" by the Oregon Chapter of the National Society of Professional Engineers.

He is author of more than 50 published papers and technical discussions on metallurgy, mechanics, and research and development administration and has been a member of many national and state boards and advisory committees.

The American Council of Independent Laboratories is the association of tax-paying, third-party, analytical, testing, research, and development laboratories. Its 260 member firms, through their 500 laboratory facilities, provide engineering and scientific services to clients in industry, commerce, and government.

— *ACIL news release*

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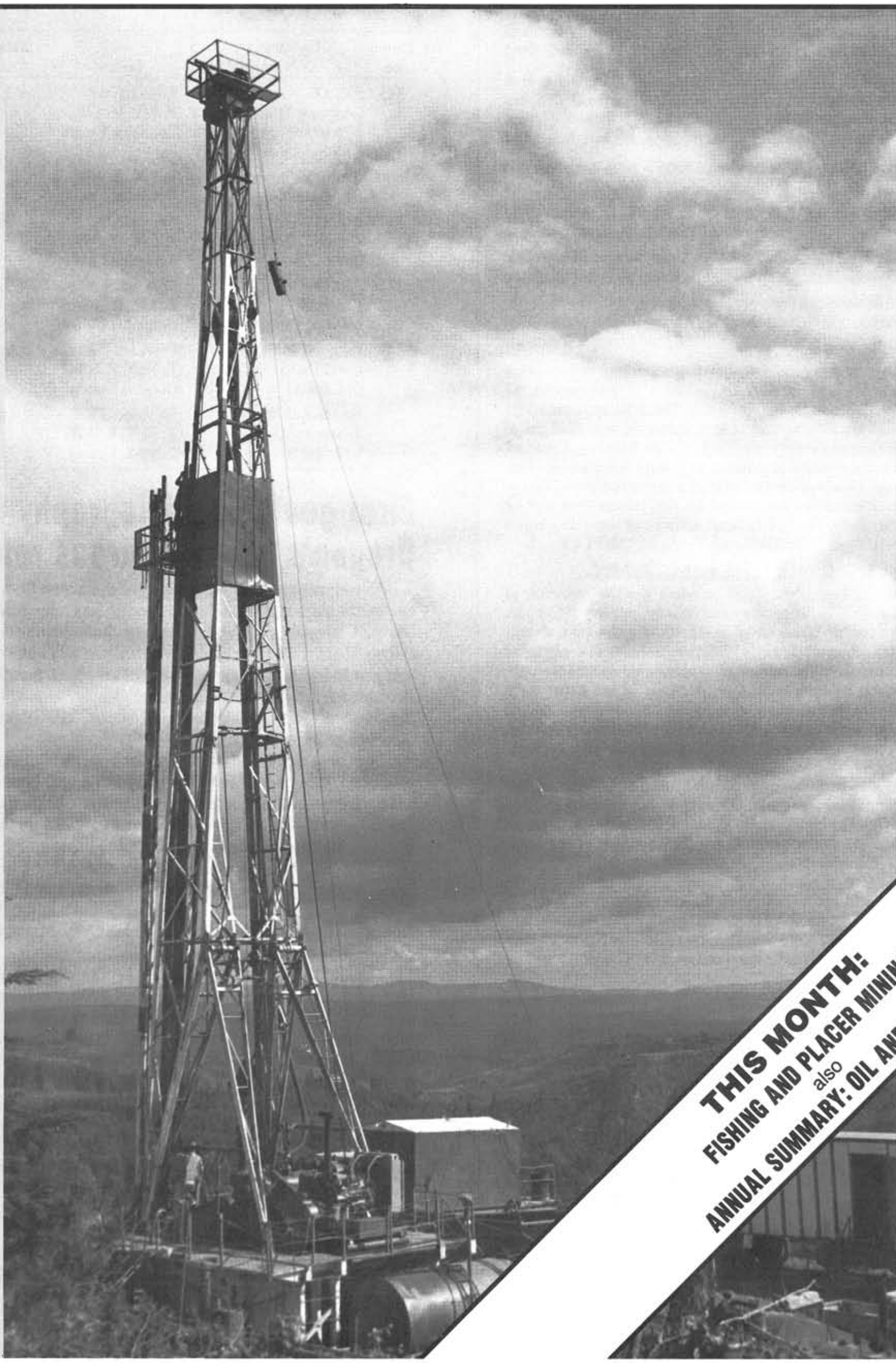

THIS MONTH:
FISHING AND PLACER MINING
also
ANNUAL SUMMARY: OIL AND GAS 1985

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

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COVER PHOTO

Taylor Drilling Company rig no. 5 on Reichhold Energy Corporation site at Mist Gas Field, Columbia County. The well was drilled to a total depth of 3,593 ft, but was a dry hole. See annual summary of oil and gas exploration and development beginning on page 29.

OIL AND GAS NEWS

Columbia County — Wildcat

ARCO Columbia County 41-6, located in NE¼ sec. 6, T. 5 N., R. 5 W., approximately 3 mi south of Birkenfeld in western Columbia County, was spudded January 15, drilled to a total depth of 2,750 ft, and plugged and abandoned January 23, 1986.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
345	ARCO Longview Fibre 13-6 009-00186	SW¼ sec. 6 T. 5 N., R. 4 W. Columbia County	Location; 3,000
346	ARCO Crown Zellerbach 23-9 009-00187	SW¼ sec. 9 T. 5 N., R. 4 W. Columbia County	Location; 2,904.
347	ARCO Crown Zellerbach 32-9 009-00188	NE¼ sec. 9 T. 5 N., R. 4 W. Columbia County	Application; 2,800.
348	ARCO Crown Zellerbach 33-9 009-00189	SE¼ sec. 9 T. 5 N., R. 4 W. Columbia County	Location; 3,041.
349	Hutchins & Marrs Great Discovery #3 019-00033	SW¼ sec. 20 T. 30 S., R. 9 W. Douglas County	Application; 3,500.
350	Hutchins & Marrs Discovery #3 019-00034	NE¼ sec. 17 T. 30 S., R. 9 W. Douglas County	Application; 6,000.

□

First geologic bibliography for Oregon's offshore areas released

A comprehensive bibliography of the ocean floor off Oregon and of the adjacent continental margin has been released by the Oregon Department of Geology and Mineral Industries (DOGAMI). The new release is published as a colored map with text printed on both front and back of the sheet. Entitled *Geologic Bibliography and Index Maps of the Ocean Floor off Oregon and the Adjacent Continental Margin,* it is map GMS-39 in DOGAMI's Geological Map Series.

The new publication is the first such bibliography ever produced. It is part of the efforts by State and Federal research teams investigating the newly expanded offshore areas under United States jurisdiction proclaimed in 1983 as the Exclusive Economic Zone (EEZ). It was produced through the joint efforts of the U.S. Minerals Management Service (MMS), the College of Oceanography of Oregon State University, and DOGAMI. The authors were OSU marine geologists C.P. Peterson and L.D. Kulm and DOGAMI staff geologist J.J. Gray. Major funding was provided by MMS.

The list of 361 citations of the bibliography is comprehensive, encompassing a wide variety of geologic subjects such as economic geology, geophysics, and tectonics. It is correlated with two index maps (scales 1:1,000,000 and 1:2,000,000) on which specific studies are outlined in seven colors on a bathymetric/topographic base. Finally, a subject index makes the references accessible under specific topics.

The new publication, DOGAMI map GMS-39, is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5530. The purchase price is $5. Orders under $50 require prepayment. □

Fishing and placer mining: Are they compatible?

by Allen H. Throop, Reclamationist, Oregon Department of Geology and Mineral Industries, Albany, and Allan K. Smith, Assistant Fisheries Biologist, Oregon Department of Fish and Wildlife, Grants Pass

INTRODUCTION

Placer miners and fishermen have often been at odds with each other over the years. On one hand, the fishermen claim that placer mining ruins the creek; on the other hand the miners maintain that their operations often enhance the fish values of a stream. Fish population surveys were recently conducted to look at the effects of mining on the fish in Sucker Creek in Josephine County. Preliminary results indicate that, in this case, anyway, the truth lies somewhere between the two extremes.

A section of Sucker Creek was completely relocated during mining. Three years after the relocation, coho salmon and steelhead have returned, but their numbers are not equal to those in unmined sections of the stream. The purpose of this article is to relate the findings of the population surveys for this site. Comparing the value of the mining against the damage done to the fish and to the fish habitat is beyond the scope of this article.

Sucker Creek is a tributary of the Illinois River between Cave Junction and the Oregon Caves (Figure 1). The area surveyed lies at the bottom of steep-sided, fir-covered mountains. Precipitation ranges up to 70 in. per year.

The climate and topography combine to make excellent anadromous fish spawning habitat with cool, free-flowing streams protected from the sun by the mountains, large fir trees,

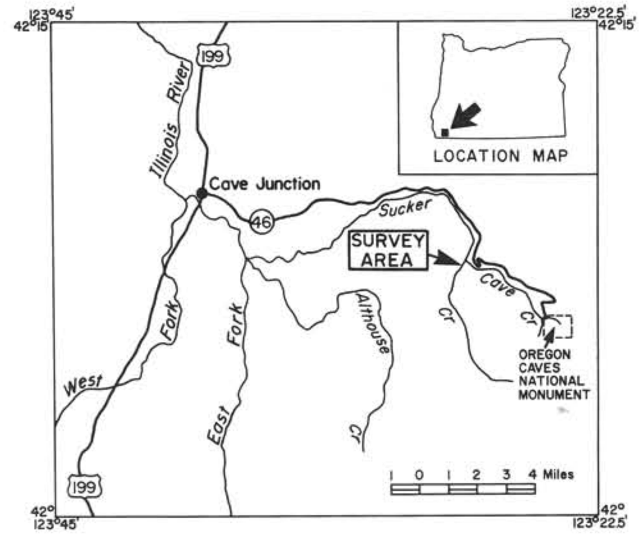


Figure 1. Location map of the fish-survey area on Sucker Creek.

Figure 2. The electrofisher in the background stuns the fish so the netter can catch them.

and a thick understory of alders and willows. The same natural topography and abundant water combined with a favorable geology led to the formation of significant placer gold deposits along Sucker and Althouse Creeks, the major drainages of the area.

Gold mining began in the area in the 1850's. Almost certainly the entire stream bed and most of the valley gravels were mined prior to 1950. Surface mining was the most common method, but evidence turned up during recent mining indicates that the original miners also used underground mining techniques to recover gold from the top of the bed rock without moving all the gravels.

In 1979, large-scale mining was revived near the junction of Sucker and Cave Creeks. For three years the miners processed all available gravel along a ½-mi stretch of the valley. During the operation, the creek was relocated along the west edge of the valley floor. This mine was one of four then operating along a 1-mi stretch of Sucker Creek's 25-mi length.

Although no fish population information was collected prior to stream relocation, the Oregon Department of Fish and Wildlife and the Oregon Department of Geology and Mineral Industries decided in the spring of 1985 to compare the fish populations of Sucker Creek upstream from the mine with a portion of relocated stream. The techniques used in this study and the results are given below.

METHODS AND MATERIALS

On July 3 and September 12, 1985, two areas on Sucker Creek were sampled using standard Fish and Wildlife sampling procedures. The Smith-Root Model V-A backpack electrofisher used (Figure 2) consists of a 12-volt motorcycle battery, a transformer, and positive and negative electrodes. Output was approximately 325 volts of pulsed DC current at 60 cycles per second. The backpack was carried by one individual who guided the positive electrode (a 12-in. copper hoop on the end of a 6½-ft-long rod). The negative electrode, a chain with copper straps attached at the end, was dragged behind. Fish were attracted to the positive electrode, stunned by the shock, netted by other party members, and held in a bucket. The fish recovered from the electric shock in a matter of seconds and were subsequently identified, counted, and released (Figure 3). A sample of up to 30 individuals of each age and species was measured for length.

Each survey area was about 150 yd long. In the undisturbed area, the stream banks were covered with stands of alders, willows, and annual plants. Woody debris was abundant in the stream. This section also had undercut banks and side channels. Overall, the channel was narrower and deeper than the disturbed section. In contrast, the banks of the relocated channel had very small alders and willows as stream-side vegetation and only one large piece of woody debris; there were no side channels in the relocated section.

Figure 3. A juvenile steelhead is measured before being released. A typical-size cottid is visible in the bucket.

RESULTS AND DISCUSSION

A summary of the sampling results appears in Table 1. Steelhead fry (young of the year) were abundant in both survey areas in July and September. Steelhead fry were more abundant in the relocated area in both months because they prefer shallow water in a riffle; there was much more of this type of habitat in the rechanneled area. Steelhead juveniles (older than one year) were found in greater numbers in the undisturbed area, because they were much larger than the fry and required deeper water and cover. Deep water and cover were absent in the relocated area. The presence of multiple ages in a steelhead population is an indicator of a healthy, balanced population.

Table 1. *Fish captured in Sucker Creek in 1985.*

Undisturbed area species	No. counted July 3	No. counted Sept. 12	Total
Steelhead fry	30	33	63
Steelhead juvenile	9	13	22
Coho fry	4	46	50
Cottid (all ages)	43	20	63
Pacific giant salamander	2	2	4
Lamprey ammocete	0	1	1
Disturbed area species	**No. counted July 3**	**No. counted Sept. 12**	**Total**
Steelhead fry	66	52	118
Steelhead juvenile	5	3	8
Coho fry	2	19	21
Cottid (all ages)	163	66	229
Pacific giant salamander	0	1	1
Lamprey ammocete	0	0	0

Coho fry in the undisturbed area outnumbered those in the rechanneled area, because they prefer habitat with pools and cover much more strongly than do steelhead fry. Many of the 19 coho captured in the rechanneled area in September were under one root wad.

Cottids, small, bottom-dwelling nongame fish popularly known as sculpins, were found in far greater numbers in the disturbed area. They were so abundant in September that many escaped capture by the netters. These fish live in areas of large gravel and small rubble where they can hide under rocks. They usually are not found in pools, on sandy or silt bottoms, or on bed rock. The large expanses of gravel in the rechanneled area provide ideal habitat for cottids; such habitat is not ideal for coho.

The actual moving of the streambed during mining destroyed spawning habitat, eggs, and fry in the gravel during the year it was moved. The production of insects, the primary food of young steelhead and salmon, was also temporarily eliminated.

Removal of vegetation deprives the fish of cooling shade, removes the primary source of terrestrial insects for food, and allows for increased stream-bank erosion, which in turn adds more silt to the stream. Revegetation of the mining site after the gold is extracted is very important. This may involve putting stored topsoil and overburden back onto recontoured gravels and planting the area with grass, alders, willows, or other plants. Each mining operation is unique and requires individual planning so that fish and fish habitat can be protected or restored. Close cooperation between the miners and the natural-resource agen-

*(Continued on page 34, **Fish**)*

Oil and gas exploration and development in Oregon, 1985

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

ABSTRACT

Oil and gas leasing in Oregon during 1985 decreased from the previous year, but the acreage under lease at year's end remained nearly unchanged. Crook County was the site of the most new federal leasing.

Applications for permits to drill were up sharply, while drilling also showed an increase. Twenty-six wells and one redrill were drilled during the year. Of these wells, 63 percent were in the Mist Gas Field in Columbia County. Two wells exceeded 11,000 ft in total depth. Eleven companies carried out exploration resulting in eight new completions. These producers were drilled by ARCO and Tenneco.

Production in 1985 totaled 4.08 billion cubic feet, for a value of $9.8 million.

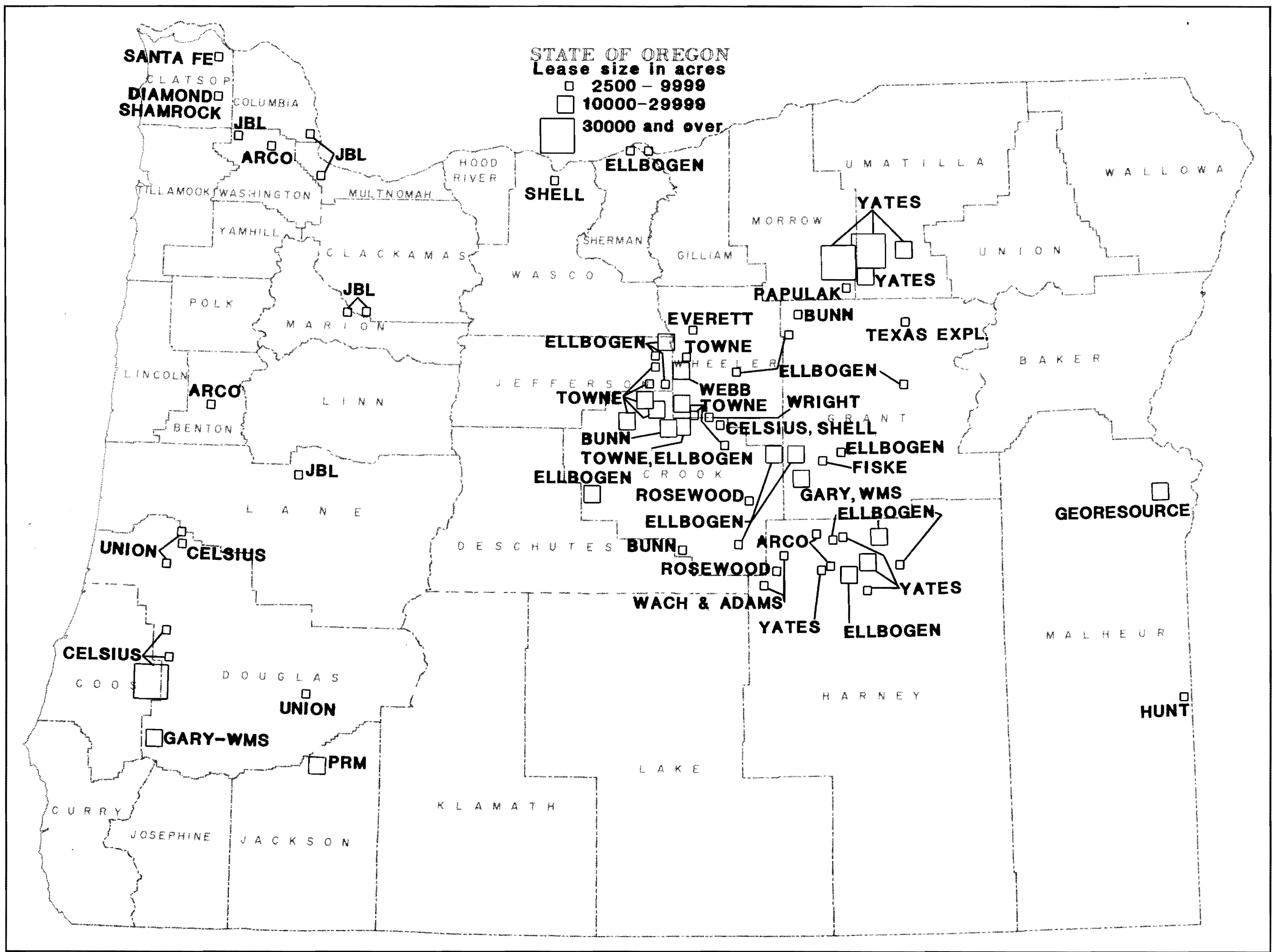
ARCO Oil and Gas Company purchased Reichhold Energy Corporation to become the predominant operator in the Mist Gas Field. The company also took over the interests of Diamond Shamrock in the field.

DOGAMI revised rules for oil and gas exploration and printed several publications related to oil and gas.

LEASING ACTIVITY

Interest in new leases on federal land dropped during 1985, but the number of acres under lease remained steady due to issuance of leases applied for in 1984. Applications in Oregon numbered 55 for a total of 246,964 acres, a drop of nearly 80 percent from 1984. Leases issued, however, increased from 237,034 acres in 1984 to 629,691 acres in 1985, a total of 174 tracts. Crook County was again the most-leased county (172,888 acres), followed by Harney County (125,646 acres) and Grant County (91,297 acres). Expired and terminated leases during the year totaled 768,644 acres, somewhat less than the previous year. By year's end, leased federal land consisted of 4,023,891 acres in 1,764 tracts.

Applications for leases of state land increased in early 1985, resulting in a lease sale held on July 24 by the Oregon Division of State Lands. This was the first such auction since February 1982. Acreage in nine counties was leased, for a total of 58,662 acres on 183 leases. A top bid of $42 per acre in Columbia County helped bring the total bonus bids to $41,192. Most acreage receiving bids was in the Mist Gas Field area. On December 31,



Map showing major oil and gas leasing in Oregon, 1985. Map shows acreage applied for, issued, and assigned. Withdrawals not shown. Data courtesy Greater Columbia LANDATA.

there were 794 state oil and gas leases in effect, encompassing 301,080 acres. Lease rental income for the year was $368,401, and Clatsop County had the most state acreage under lease of any county. Surrendered leases amounted to 43,474 acres during 1985.

There were no new significant county lease sales or auctions during the year.

DRILLING

Twenty-six oil and gas wells were drilled in the state in 1985, plus one redrill. This is an increase of ten wells, or nearly 60 percent, over 1984. This increase continues the upward trend started in 1984 which followed three years of decreased activity. Eighteen wells and the redrill were within the boundaries of the Mist Gas Field, a pattern that has continued since the field discovery in 1979. Two additional wells were located nearby in Columbia and Clatsop Counties, while the remaining five were scattered in western and central Oregon (see map).

Driller and roughnecks running drill pipe into Columbia County 23-35, Mist Gas Field. The well was later plugged and abandoned.

Wells in the Willamette Valley include one drilled near St. Louis by Oregon Natural Gas Development (2,511 ft, abandoned) and two drilled north of Eugene, one by Leavitt Exploration and one by Ty Settles. The wells, drilled to 2,871 ft and 1,600 ft, respectively, were also dry. But they indicate a continued interest in the valley, where wells have been drilled each year since 1979.

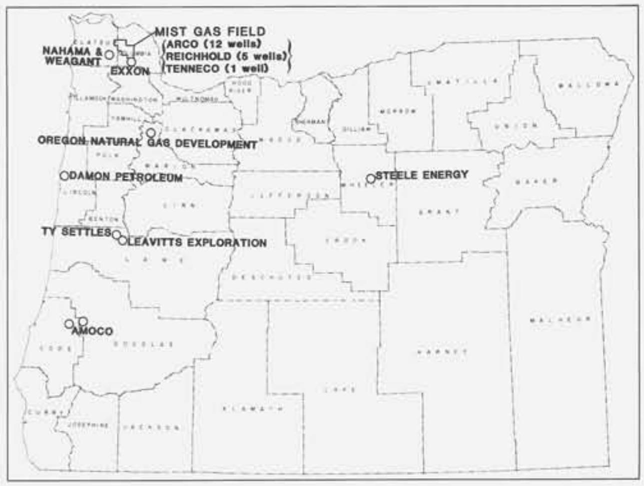
Permitting of wells was also up in 1985, with 53 permits to drill issued (Table 1). This nearly doubles the number of 1984 permits. Fifteen expired permits were canceled during the year (Table 2).

Eleven different operators explored in the state, with four as new operators: ARCO, Exxon, Settles, and Tenneco. ARCO was very successful, with seven new completions in Mist Gas Field, while Tenneco had one completion. All other wells were dry holes.

Two wells exceeded 11,000 ft in depth: one drilled by Amoco in Douglas County and one by Exxon in Columbia County. Both were dry holes but helped to boost the total drilled footage to 84,169 ft, the highest since 1982. For two wells in progress at the beginning of 1985, only the footage drilled during the year is included in the total. The average well depth was about 3,500 ft, slightly deeper than in 1984.

DISCOVERIES AND GAS PRODUCTION

The Mist Gas Field experienced its best year to date in terms of number of new wells completed to production. Eight new producers were drilled, and three were on line by year's end. These wells represent seven new pools, continuing the trend of small one- or two-well pools. Two of the new wells, ARCO



Oil and gas drilling sites in Oregon, 1985.

Crown Zellerbach 23-15 and 31-16, expanded the extent of production for a distance of nearly 5 mi to the southeast from previous production. Due to the nitrogen content of these wells, however, they have not yet been put on line.

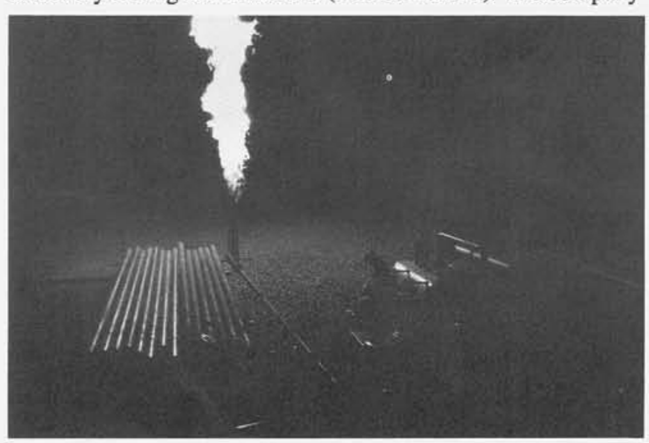
ARCO and Tenneco are the operators of all the new producers; both companies are new to Oregon exploration. Much of the ARCO activity is the result of its takeover of Reichhold Energy holdings during the year (see below).

By the end of the year, the number of wells on line increased from six to nine. This will increase by several more wells in 1986 as pipelines are installed to the remaining 1985 completions. Only two wells, Columbia County 13-34 and Longview Fibre 12-33, from the original northern part of the field remain in production.

Production for the year totaled 4.08 billion cubic feet (Bcf), an increase from the 1984 total of 2.79 Bcf. The rate averaged 11.1 million cubic feet per day (MMcfd), bringing the cumulative field production at the end of 1985 to 23.3 Bcf. Wellhead gas prices varied between $0.232 and $0.281 per therm during the year, and the total value of gas produced was $9.8 million.

ARCO PURCHASES REICHHOLD

After sharing in production of a Reichhold well in 1984 due to a farmout agreement, ARCO began drilling its own wells last year. The first attempt, Columbia County 44-21, was a new pool discovery testing at 1.8 MMcfd (Tables 1 and 3). The company



Initial production test of Tenneco Oil Company's Columbia County 41-28, Tenneco's first completed well in the state. The tested flow was 1.1 million cubic feet per day.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1985*

Permit no.	Operator, well, API number	Location	Status, depth (ft) TD = total depth PTD = proposed TD RD = redrill
237	ARCO Oil & Gas Co.* Columbia County 23-22 009-00116	SW¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,028.
268	Amoco Production Co. Weyerhaeuser B-1 019-00027	SW¼ sec. 13 T. 25 S., R. 9 W. Douglas County	Abandoned, dry holes; TD: 11,330.
275	Oregon Nat. Gas Dev. DeShazer 13-22 047-00018	SW¼ sec. 22 T. 5 S., R. 2 W. Marion County	Abandoned, dry holes; TD: 2,511.
276	Steele Energy Corp. Keys 1 069-00008	NW¼ sec. 28 T. 9 S., R. 23 E. Wheeler County	Idle; TD: 6,539.
277	ARCO Oil & Gas Co.* Longview Fibre 23-36 009-00132	SW¼ sec. 36 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 1,879.
279	Reichhold Energy Corp. Longview Fibre 42-22 009-00134	NE¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,278.
281	Leavitt Exploration Jackson 1 039-00006	NW¼ sec. 14 T. 19 S., R. 4 W. Lane County	Permit issued; PTD: 3,000.
282	Leavitt Exploration Jackson 2 039-00007	SE¼ sec. 11 T. 19 S., R. 4 W. Lane County	Permit issued; PTD: 3,000.
283	ARCO Oil & Gas Co. Banzer 34-16 009-00136	SE¼ sec. 16 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 4,902.
284	ARCO Oil & Gas Co. Columbia County 44-21 009-00137	SE¼ sec. 21 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 4,500.
285	Ty Settles Cindy 1 039-00008	NW¼ sec. 23 T. 16 S., R. 5 W. Lane County	Idle; TD: 1,600.
286	Ty Settles Cindy 2 039-00009	SW¼ sec. 23 T. 16 S., R. 5 W. Lane County	Application; PTD: 2,500.
287	Reichhold Energy Corp. Columbia County 43-34 009-00138	SE¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,100. RD: 2,225.
288	Nahama & Weagant Jewell 1-23 007-00017	SW¼ sec. 23 T. 5 N., R. 7 W. Clatsop County	Abandoned, dry hole; TD: 3,190.
289	Reichhold Energy Corp. Crown Zellerbach 34-26 009-00139	SE¼ sec. 26 T. 5 N., R. 4 W. Columbia County	Abandoned, dry hole; TD: 5,838.
290	Reichhold Energy Corp. Columbia County 23-35 009-00140	NW¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Abandoned, dry hole; TD:3,593.
291	Hutchins & Marrs Discovery 1 019-00031	NE¼ sec. 17 T. 30 S., R. 9 W. Douglas County	Permit issued; PTD: 6,000.
292	Reichhold Energy Corp. Columbia County 33-8 009-00141	SE¼ sec. 8 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 3,612.
293	Hutchins & Marrs Great Discovery 2A 019-00032	NW¼ sec. 20 T. 30 S., R. 9 W. Douglas County	Application; PTD: 6,000. Permit denied. (Table 2)
294	Oregon Nat. Gas Dev. Tesch 44-21 047-00019	SE¼ sec. 21 T. 5 S., R. 2 W. Marion County	Permit issued; PTD: 3,000.
295	ARCO Oil & Gas Co. Columbia County 23-19 009-00142	SE¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 3,440.
296	ARCO Oil & Gas Co.* Crown Zellerbach 12-1 009-00143	NW¼ sec. 1 T. 5 N., R. 5 W. Columbia County	Completed, gas; TD: 1,721.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1985 — continued*

Permit no.	Operator, well API number	Location	Status, depth (ft) TD = total depth PTD = proposed TD RD = redrill
297	Hutchins & Marrs Georgia Pacific 1 011-00021	NE¼ sec. 14 T. 30 S., R. 10 W. Coos County	Permit issued; PTD: 6,000.
298	Tenneco Oil & Co. Columbia County 11-28 009-00145	NW¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,500.
299	Tenneco Oil Co. Columbia County 14-28 009-00145	SE¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,500.
300	Tenneco Oil Co. Columbia County 33-28 009-00146	SE¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,000.
301	Tenneco Oil Co. Columbia County 41-28 009-00147	NE¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,178.
302	Tenneco Oil Co. Columbia County 42-28 009-00148	NE¼ sec. 28 T. 6 N., R. 5 W. Columbia County	Application; PTD: 3,000.
303	ARCO Oil & Gas Co. Columbia County 11-31 009-00149	NW¼ sec. 31 T. 6 N., R. 3 W. Columbia County	Permit issued; PTD: 12,000.
304	ARCO Oil & Gas Co. Columbia County 33-28 009-00150	SE¼ sec. 28 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 5,500.
305	ARCO Oil & Gas Co. Columbia County 41-14 009-00151	NE¼ sec. 14 T. 4 N., R. 3 W. Columbia County	Permit issued; PTD: 12,000.
306	ARCO Oil & Gas Co. Columbia County 43-3 009-00152	SW¼ sec. 3 T. 4 N., R. 3 W. Columbia County	Permit issued; PTD: 12,000 (later withdrawn by ARCO)
307	ARCO Oil & Gas Co.* Crown Zellerbach 31-16 009-00153	NE¼ sec. 16 T. 5 N., R. 4 W. Columbia County	Completed, gas; TD: 2,867.
308	Exxon Corp. Columbia County 1 009-00154	NE¼ sec. 29 T. 5 N., R. 3 W. Columbia County	Permit issued; PTD: 4,000.
309	Exxon Corp. GPE Federal 1 009-00155	SW¼ sec. 3 T. 4 N., R. 3 W. Columbia County	Application; PTD: 10,000. Permit denied. (Table 2)
310	Exxon Corp. GPE Federal 2 009-00156	SE¼ sec. 3 T. 4 N., R. 3 W. Columbia County	Application; PTD: 6,000. Permit denied. (Table 2)
311	Exxon Corp. Crown Zellerbach 1 009-00157	NE¼ sec. 28 T. 5 N., R. 3 W. Columbia County	Permit issued; PTD: 4,000.
312	Exxon Corp. GPE Federal 3 009-00158	SW¼ sec. 35 T. 5 N., R. 3 W. Columbia County	Permit issued; PTD: 4,000.
313	ARCO Oil & Gas Co. Columbia County 22-19 009-00159	NW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,500.
314	ARCO Oil & Gas Co. Scherf 41-21 009-00160	NE¼ sec. 21 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,200.
315	Leavitt Exploration Falk 3 039-00010	NE¼ sec. 13 T. 16 S., R. 5 W. Lane County	Application; PTD: 2,500.
316	Leavitt Exploration Jessie 1 039-00011	SW¼ sec. 13 T. 16 S., R. 5 W. Lane County	Application; PTD: 2,500.
317	Leavitt Exploration Merle 1 039-00012	NE¼ sec. 25 T. 16 S., R. 5 W. Lane County	Abandoned, dry hole; TD: 2,871.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1985 — continued*

Permit no.	Operator, well API number	Location	Status, depth (ft) TD = total depth PTD = proposed TD RD = redrill
318	ARCO Oil & Gas Co.* Columbia County 24-23 009-00161	SW¼ sec. 23 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,600.
319	ARCO Oil & Gas Co. Columbia County 14-18 009-00162	SW¼ sec. 18 T. 4 N., R. 3 W. Columbia County	Application; PTD: 12,000.
320	Exxon Corp. GPE Federal Com. 1 009-00163	SE¼ sec. 3 T. 4 N., R. 3 W. Columbia County	Abandoned, dry hole; TD: 11,276.
321	Tenneco Oil Co. Columbia County 12-15 009-00164	NW¼ sec. 15 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 1,000.
322	Tenneco Oil Co. Columbia County 24-10 009-00165	SW¼ sec. 10 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 1,000.
323	Amoco Production Co. Weyerhaeuser F-1 011-00022	NE¼ sec. 10 T. 25 S., R. 10 W. Coos County	Abandoned, dry hole; TD: 4,428.
323	ARCO Oil & Gas Co.* Crown Zellerbach 23-15 009-00166	SW¼ sec. 15 T. 5 N., R. 4 W. Columbia County	Completed, gas; TD: 2,770.
325	ARCO Oil & Gas Co.* Columbia County 41-6 009-00167	NE¼ sec. 6 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 2,500.
326	ARCO Oil & Gas Co.* Columbia County 33-6 009-00168	SE¼ sec. 6 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 2,500.
327	Damon Petroleum Longview Fibre 3 041-00006	NW¼ sec. 21 T. 9 S., R. 11 W. Lincoln County	Abandoned, dry hole; TD: 3,040.
328	Exxon Corp. Columbia County B-1 009-00169	SW¼ sec. 2 T. 4 N., R. 3 W. Columbia County	Permit issued; PTD: 12,000.
329	Exxon Corp. Columbia County C-1 009-00170	NW¼ sec. 14 T. 4 N., R. 3 W. Columbia County	Permit issued; PTD: 6,800.
330	Diamond Shamrock* Columbia County 33-35 009-00171	SE¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD: 3,100.
331	ARCO Oil & Gas Co.* Columbia County 43-32 009-00172	SE¼ sec. 32 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,500.
332	ARCO Oil & Gas Co.* Columbia County 11-34 009-00173	NW¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,500.
333	ARCO Oil & Gas Co.* Crown Zellerbach 41-2 009-00174	NE¼ sec. 2 T. 5 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,109.
334	ARCO Oil & Gas Co.* Columbia County 13-3 009-00175	SW¼ sec. 3 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 2,500.
335	ARCO Oil & Gas Co. Columbia County 41-24 009-00176	NE¼ sec. 24 T. 4 N., R. 4 W. Columbia County	Permit issued; PTD: 12,000.
336	ARCO Oil & Gas Co. Columbia County 22-7 009-00177	NW¼ sec. 7 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 4,000.
337	ARCO Oil & Gas Co.* Columbia County 22-27 009-00178	NW¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 2,500.
338	ARCO Oil & Gas Co.* Longview Fibre 23-25 009-00179	SW¼ sec. 25 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 1,979.
339	ARCO Oil & Gas Co.* Columbia County 32-32 009-00180	NE¼ sec. 32 T. 6 N., R. 5 W. Columbia County	Completed, gas; TD: 2,711.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1985 — continued*

Permit no.	Operator, well API number	Location	Status, depth (ft) TD = total depth PTD = proposed TD RD = redrill
340	ARCO Oil & Gas Co. Columbia County 14-30 009-00181	SW¼ sec. 30 T. 6 N., R. 3 W. Columbia County	Permit issued; PTD: 6,300. (directional)
341	ARCO Oil & Gas Co. Longview Fibre 41-35 009-00182	NE¼ sec. 35 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 1,920.
342	ARCO Oil & Gas Co. Columbia County 31-27 009-00183	NE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,115.
343	ARCO Oil & Gas Co. Longview Fibre 34-25 009-00184	SE¼ sec. 25 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,020.
344	ARCO Oil & Gas Co. Columbia County 41-2-1 009-00185	NE¼ sec. 2 T. 5 N., R. 5 W. Columbia County	Permit issued; PTD: 2,000. (directional)

*Formerly Reichhold Energy well

Drill pipe location for Reichhold Energy Corporation's Columbia County 23-35.

had extensive lease holdings in the southern part of the field and continued exploration with Banzer 34-16 and Columbia County 23-19, which proved to be dry holes.

During the year, Reichhold Chemicals, Inc., parent company of Reichhold Energy Corporation, decided to sell the subsidiary, resulting in the eventual purchase by ARCO Oil and Gas Company, effective October 1, 1985. ARCO took over all leases, wells, and permits to drill held by Reichhold.

Reichhold Energy was formed in January 1975 to explore for energy resources to supply the Reichhold Chemicals fertilizer plant in St. Helens, Oregon. Their efforts, along with those of their partners, Oregon Natural Gas Development and Diamond Shamrock, resulted in the Mist Gas Field discovery in 1979. The company sold the St. Helens plant in early 1985.

After the sale of Reichhold Energy, Diamond Shamrock decided to sell its Oregon holdings, which ARCO also bought late in the year. This included leases and permits formerly held by Diamond Shamrock. As a result, the operators in the field now consist of ARCO, Oregon Natural Gas Development, and Tenneco.

OTHER ACTIVITY

The Northwest Petroleum Association remained very active in spite of the downturn in the industry. Membership stood at 165 at the end of the year. In addition to monthly meetings, the organization held two symposia during the year. One on the Mist Gas Field area consisted of a day devoted to papers on many aspects of field development, from leasing to geology to economics, followed by a day in the field to see the geology of the region.

Table 2. *Canceled and denied permits, 1985*

Permit no.	Operator, well, API number	Location	Issue date	Cancellation date	Reason
228	Reichhold Energy Corp. Columbia County 23-28 009-00111	SW¼ sec. 28 T. 7 N., R. 5 W. Columbia County	3-18-83	3-18-85	Expired
229	Reichhold Energy Corp. Columbia County 23-35 009-00112	SW¼ sec. 35 T. 7 N., R. 5 W. Columbia County	3-4-83	3-4-85	Expired
231	Reichhold Energy Corp. Longview Fibre 23-12 009-00114	SW¼ sec. 12 T. 6 N., R. 5 W. Columbia County	3-4-83	3-4-85	Expired
250	Reichhold Energy Corp. Longview Fibre 33-36 009-00120	SW¼ sec. 36 T. 6 N., R. 5 W. Columbia County	9-21-83	9-27-85	Expired
251	Reichhold Energy Corp. Grimsbo 11-16 009-00121	NW¼ sec. 16 T. 6 N., R. 5 W. Columbia County	9-21-83	9-27-85	Expired
254	Oregon Nat. Gas Dev. Dougherty 1-21 049-00001	NE¼ sec. 21 T. 1 S., R. 27 E. Morrow County	12-9-83	12-9-85	Expired
257	Reichhold Energy Corp. Columbia County 21-27 009-00125	NW¼ sec. 27 T. 6 N., R. 5 W. Columbia County	2-7-84	3-1-85	Expired
269	Reichhold Energy Corp. Longview Fibre 13-23 009-00131	SW¼ sec. 23 T. 6 N., R. 5 W. Columbia County	8-21-84	8-23-85	Expired
270	Hutchins & Marrs Great Discovery 3 019-00028	SW¼ sec. 20 T. 30 S., R. 9 W. Douglas County	8-23-84	8-23-85	Expired
271	Hutchins & Marrs Great Discovery 4 019-00029	SW¼ sec. 20 T. 30 S., R. 9 W. Douglas County	8-23-84	8-23-85	Expired
272	Hutchins & Marrs Great Discovery 5 019-00030	SW¼ sec. 20 T. 30 S., R. 9 W. Douglas County	8-23-84	8-23-85	Expired
273	Oregon Nat. Gas Dev. Buck 44-16 047-00016	SW¼ sec. 16 T. 5 S., R. 2 W. Marion County	10-17-84	12-20-85	Expired
274	Oregon Nat. Gas Dev. Cunningham 32-21 047-00017	NE¼ sec. 21 T. 5 S., R. 2 W. Marion County	10-17-84	12-20-85	Expired
278	ARCO Oil & Gas Co.* Invest. Mgmt. 22-20 009-00133	NW¼ sec. 20 T. 6 N., R. 4 W. Columbia County	11-27-84	12-23-85	Expired
280	ARCO Oil & Gas Co.* Columbia County 44-10 009-00135	SW¼ sec. 10 T. 6 N., R. 5 W. Columbia County	11-27-84	12-23-85	Expired
293	Hutchins & Marrs Great Discovery 2A 019-00032	NW¼ sec. 20 T. 30 S., R. 9 W. Douglas County			Permit denied due to idle well in same drilling unit.
309	Exxon Corp. GPE Federal 1 009-00155	SW¼ sec. 3 T. 4 N., R. 3 W. Columbia County			Permit denied due to existing permit in drilling unit.
310	Exxon Corp. GPE Federal 2 009-00156	SE¼ sec. 3 T. 4 N., R. 3 W. Columbia County			Permit denied due to existing permit in drilling unit.

*Formerly Reichhold Energy well.

A second symposium concentrated on Outer Continental Shelf (OCS) development off Oregon and Washington. This was cosponsored by the Portland Chamber of Commerce Energy Committee and featured speakers from the Western Oil and Gas Association, Minerals Management Service, Exxon, and Governor Atiyeh's office. The federal OCS leasing schedule lists Oregon for leasing as soon as 1991.

The major Oregon Department of Geology and Mineral Industry Governing Board actions in 1985 regarding oil and gas exploration were the adoption of temporary and permanent rule changes. Final permanent changes became effective in November and included changes to definitions, changes to conditions for permit to drill, specific requirements for blowout preventers, standards for plugging a lost radioactive source, revision of

Table 3. *New completed wells, 1985*

Well	Initial production (MMcfd)	Date completed
ARCO Columbia County 32-32	2.2	Nov. 13, 1985
ARCO Columbia County 44-21	1.8	Feb. 10, 1985
ARCO Crown Zellerbach 12-1	1.1	June 30, 1985
ARCO Crown Zellerbach 31-16	5.9	July 30, 1985
ARCO Crown Zellerbach 23-15	4.1	Dec. 10, 1985
ARCO Longview Fibre 23-25	1.2	Dec. 16, 1985
ARCO Longview Fibre 23-36	2.3	Jan. 8, 1985
Tenneco Columbia County 41-28	1.1	Sept. 27, 1985

Table 4. *Production: Mist Gas Field*

1985 Production (Mcf)			
January	271,717	July	385,157
February	242,077	August	386,511
March	301,885	September	405,563
April	300,775	October	346,657
May	364,072	November	361,910
June	372,148	December	348,376
Cumulative (1985):		4,086,848 Mcf	
Cumulative (1979-1985):		23,306,184 Mcf	

directional drilling rule, change of flow-testing rule, change in conditions for unlawfully abandoned status, bond increases, and special spacing rules for Columbia and Clatsop Counties.

DOGAMI released several publications in the Oil and Gas Investigations series during the year. Additions to the series included OGI-10, *Mist Gas Field: Exploration and Development, 1979-1984;* OGI-13, *Biostratigraphy of Exploratory Wells, Southern Willamette Basin;* and OGI-14, *Oil and Gas Investigation of the Astoria Basin, Clatsop and North Tillamook Counties, Northwestern Oregon.* In addition, Open-File Report 0-84-2, *The Mist Gas Field Map* (1:24,000), was revised to reflect recent changes in the field. □

Study shows low coal potential in Arbuckle Mountain area

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a study of coal deposits in the Arbuckle Mountain area southeast of Heppner in Morrow County. The report concludes that the area shows little potential for hosting minable quantities of coal. There may be, however, reason to investigate the area's promise for oil and gas resources.

Geology and Coal Resources of the Arbuckle Mountain Coal Field, Morrow County, Oregon, has been published as DOGAMI's Open-File Report 0-86-5 (price $6) and was written by staff geologists Mark L. Ferns and Howard C. Brooks. The study was funded in part by the U.S. Bureau of Land Management and the USDA Forest Service. The 25-page text of the report describes the geology and stratigraphy of the region, its coal occurrences and the conditions of their formation, and its resource potential for coal. An accompanying blackline map shows, on its two parts, (1) the known coal prospects and the distribution of pre-Columbia River Basalt Group rocks south and southeast of Heppner (scale 1:100,000) and (2), in greater detail (scale 1:24,000), the geology of the Johnson Creek area.

The reconnaissance study indicates that sandstones exposed in the core of the Blue Mountains in this area are 2,000 ft thick. These sandstones underlie volcanic rocks and contain lignite coal beds generally less than 2 ft in thickness. Similarly aged sandstone, which occurs in the Methow and Chewaukum areas of central Washington, might be expected to occur beneath the Columbia Plateau and may constitute favorable reservoir rocks for natural gas or oil. □

December 18, 1985, fireball reported

*by Daniel J. Kraus and Richard N. Pugh**

At 8:20 Pacific Daylight Time, December 18, 1985, a large fireball crossed Oregon from Tillamook on the coast to Baker near the Oregon-Idaho border.

The path was from west-northwest to east-southeast. Reports on the angle of descent varied from 20° to 90°. The steeper angles were reported mostly from eastern Oregon.

Almost all of the observers reported the fireball as brilliant, casting shadows. A trained observer in Bend, Oregon, reported a magnitude of at least -8. The fireball seemed to illuminate the northern half of Oregon.

The apparent diameter reported ranged from ¼ to ¾ of a full moon.

Most observers on the west side of the Cascade Mountains saw a round object, while most observers east of the Cascades saw a pear-shaped fireball. One-fourth of the reports had a white fireball, the other three-fourths had a blue-green object. Few people in western Oregon saw a tail, while most observers in eastern Oregon reported a white tail of varying lengths.

Most observers who saw termination reported sparks and fragmentation. The number of fragments reported ranged from 2 to 25.

There were no sounds reported either during or after the event. □

*Dan Kraus is Research Assistant Astronomer at University of Oregon's Pine Mountain Observatory, phone (503) 382-8331. Dick Pugh is Science Department Chairman at Cleveland High School, Portland, Oregon, phone (503) 280-5120. Both are correspondents to the Smithsonian Institution Scientific Event Alert Network (SEAN), a bulletin on short-term phenomena.

Mined Land Reclamation office moves

The Mined Land Reclamation office has moved into temporary new quarters, where it will be until June 1, 1986. The temporary street address is 1800 Geary Street SE. The permanent street address after June 1 will be 1534 Queen Avenue SE, Albany, OR 97321. Rather than change mailing addresses in June, the office has made arrangements to have the Queen Avenue address be the permanent mailing address from now on. The phone number is unchanged: (503) 967-2039. □

(Fish, continued from page 28)

cies is required to strike a balance between two conflicting uses of the resources of Oregon.

This survey does not answer many questions such as: What are the economic benefits to Cave Junction and to Oregon of gold mining versus those of fishing? What effect did all the mining have on the stream temperature and thus on the fish population? How did the turbidity caused by mining and channel relocation affect downstream fish populations? Should use of one resource be encouraged over the other?

The results of the survey indicate that the relocated stream channel is definitely less productive than the unmined area, but that fish are returning. Repeated surveys over the next three or four years should indicate how long it will take for the fish populations to stabilize in the relocated channel and whether the altered section of the channel will equal the unmined area in productivity. Results of this study apply only to the specific configuration of this relocated stream. A different configuration favoring riffles and pools might have encouraged quicker reestablishment of coho and steelhead populations. □

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

	Price	No. copies	Amount
GMS-4: Oregon gravity maps, onshore and offshore. 1967	$ 3.00		
GMS-5: Geologic map, Powers 15-minute quadrangle, Coos and Curry Counties. 1971	3.00		
GMS-6: Preliminary report on geology of part of Snake River canyon. 1974	6.50		
GMS-8: Complete Bouguer gravity anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
GMS-9: Total-field aeromagnetic anomaly map, central Cascade Mountain Range, Oregon. 1978	3.00		
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Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of DOGAMI.

COVER PHOTO

Teague Mineral Products mill on banks of Snake River at Adrian, Oregon. The mill is used for storing, grinding, sizing, and bagging bentonite and zeolite mined in several areas of southeastern Oregon. Photo shows stored raw bentonite in open shed on left, silos for storage of finished product at right center. Product from this plant is shipped bagged or in bulk, by rail or truck. See annual summary of mineral industry in Oregon beginning on next page. Photo courtesy Dave Leppert, Teague Mineral Products.

OIL AND GAS NEWS

Mist Gas Field

ARCO Oil and Gas Co. is the only active operator in the state at present. In March the company drilled Longview Fibre 13-6 to a depth of 1,473 ft in sec. 6, T. 5 N., R. 4 W. It was one mile east of completed well Crown Zellerbach 12-1, but was a dry hole. It was abandoned on March 11. The contractor was Taylor Drilling.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
351	ARCO Longview Fibre 14-25 009-00190	SW¼ sec. 25 T. 6 N., R. 5 W. Columbia County	Permit denied; spacing unit violation.
352	ARCO Columbia County 44-27 009-00191	SE¼ sec. 27 T. 6 N., R. 5 W. Columbia County	Location; 2,360.
353	ARCO Longview Fibre 43-4 009-00192	NE¼ sec. 4 T. 5 N., R. 5 W. Columbia County	Application; 3,000.
354	ARCO Columbia County 44-6 009-00193	SE¼ sec. 6 T. 6 N., R. 5 W. Columbia County	Application; 3,000.
355	ARCO Columbia County 31-7 009-00194	NE¼ sec. 7 T. 6 N., R. 5 W. Columbia County	Application; 3,000.
356	ARCO Columbia County 13-21 009-00195	SW¼ sec. 21 T. 6 N., R. 5 W. Columbia County	Application; 3,000.

□

Willamette Agate and Mineral Society displays minerals in Salem

On March 1, 1986, the Willamette Agate and Mineral Society (WAMS) of Salem installed a varied lapidary display in the Oregon Council of Rock and Mineral Clubs Case at the State Capitol building in Salem. More than 90 separate items in 36 groups include petrified wood, sagenite, carnelian, plume agate, thomsonite, pyrite, moss agate, fossils, thundereggs, nodules, limb casts, Biggs jasper, Carey plume, obsidian, opal, and jadeite.

The exhibit demonstrates several ways rocks can be enjoyed — bookends, clocks, gem trees, bracelets, necklaces, belt buckles, spheres, and mounted specimens.

Eight of the club members contributed materials from 16 Oregon counties for the display. Members arranging the exhibit were Rollin and Bettie Stearns, Al and Myrna Gardner, George Schull, and Willis Caldwell. Lyle Riggs, Agent for the Council Case; Vivian Johnson, Council Secretary; and Florence Riggs and Bernice Soules assisted.

The WAMS display will remain until May 31 and will be followed by the exhibit of Far West Lapidary and Gem Society of Coos Bay, Oregon.

On February 28, John Richardson removed the beautiful display of Richardson Recreational Ranch of Madras, which had been sponsored by Oregon Agate and Mineral Society of Portland. □

Mineral industry in Oregon, 1985

by Mark L. Ferns, Howard C. Brooks, Jerry J. Gray, and Len Ramp, Oregon Department of Geology and Mineral Industries

INTRODUCTION

The value of minerals produced in Oregon in 1985 was about $127 million, which was $10 million below the 1984 value. The decline was due in part to a six-month work stoppage at the Hanna nickel mine and smelter at Riddle during a plant modification program. Other factors involved included a drop in demand for sand, gravel, and crushed stone and a drop in prices for nearly all mineral commodities.

As in previous years, cement, sand and gravel, and stone were the main products of Oregon's mineral industry. Base-and precious-metal production from lode mines declined sharply due to the 1984 closure of the Iron Dyke and Bayhorse Mines in Baker County. Nickel from the Hanna operation remains the only metallic commodity that is currently being produced in any significant amount.

MINING ACTIVITY

Metals

A number of small gold placers were active in Baker and Grant Counties in northeastern Oregon and Josephine, Douglas, and Jackson Counties in southwestern Oregon. Most of the operations were small, and only a few produced over 50 oz of gold.

The larger productive placer mines in eastern Oregon were on Pine Creek (7)* near Hereford, on Clarks Creek (8), and on the upper Burnt River (6) in Baker County and on Boulder Creek (3) near Granite in Grant County. Numerous small operations continued in Josephine County, including a number on Josephine Creek and its tributaries (12), in the Galice area (15), and on Coffee Creek (18) in Douglas County. Proposed rules for the Wild and Scenic Illinois River Management Plan would end the use of small dredges on the Wild and Scenic stem of the Illinois River, where a number of operations have been active in past years at various sites between the U.S. National Forest boundary and the mouth of Briggs Creek.

Lode gold, silver, and base-metal production was mainly from small, intermittent operations at the Thomason Mine (5) in Baker County; the Pyx (2), Tempest (1), and Elk Heaven (4) Mines in Grant County; and the Greenback (16) and Fall Creek Gold Mine (11) in Josephine County.

The Hanna nickel smelter at Nickel Mountain (17) in Douglas County operated until mid-June, at which time it was shut down for construction of a new wet-screening plant. Renewed operations began in late November. The plant enables rapid upgrading by washing the higher grade, soft fine material off the relatively unweathered rock. The water-and-fines slurry goes through a 300-ft-diameter thickener before being transported 2½ mi down the mountain in a 10-in-diameter steel pipe to the smelter. Five centrifuges separate most of the water from the concentrate, which reportedly contains about 2.1 percent nickel.

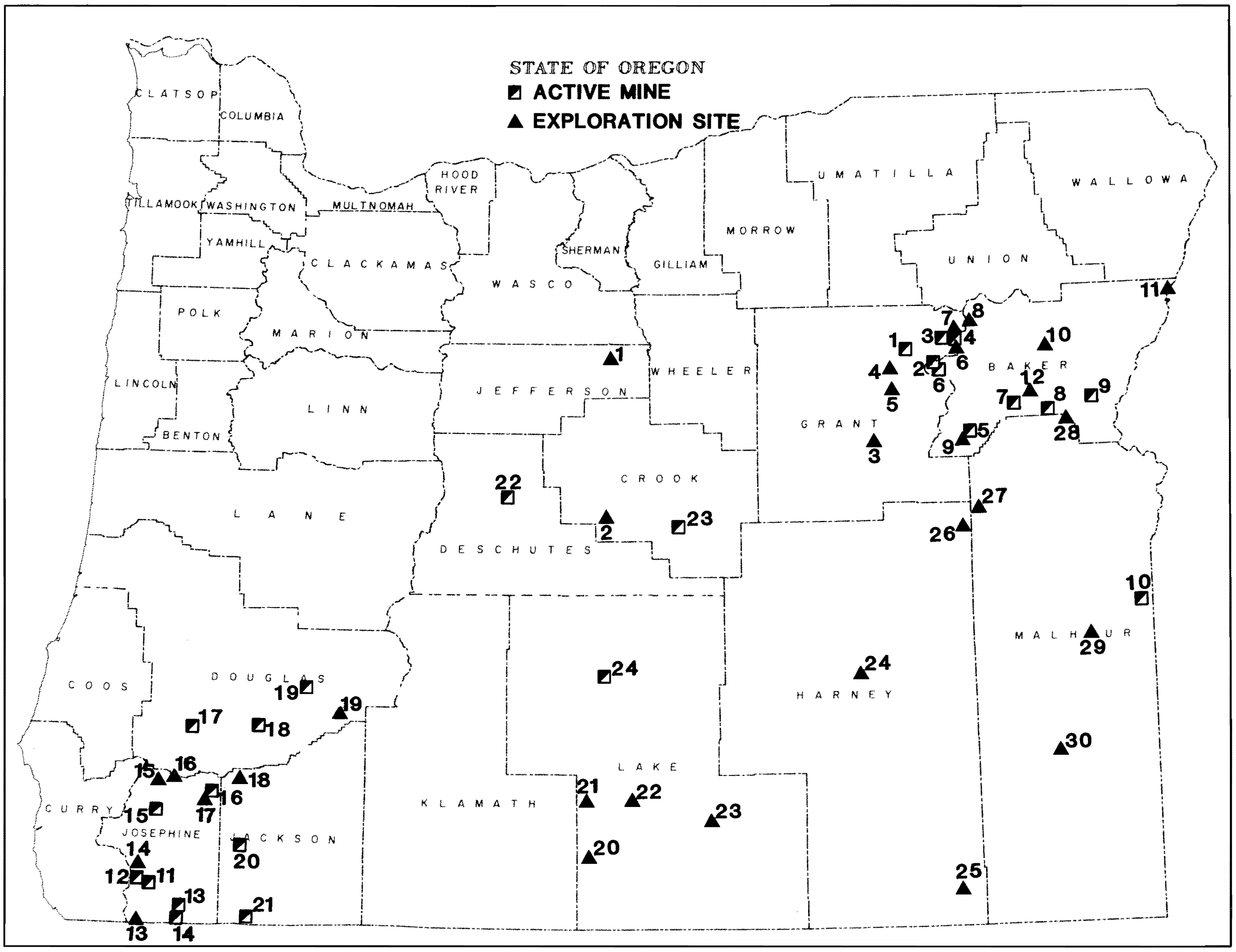
A conveyer belt is being constructed to transport ore from the lower ore body up the mountain to the wet-screening plant. A 12.2-yd^3 Marion 191 electric shovel will be used for mining about 7 million tons per year. Only about 10 percent of the material mined will be smelted. The new equipment is expected to enable Hanna to produce nickel for about $1.90 per pound.

Nonmetals

Ash Grove Cement West (9) continued to produce cement and limestone from its limestone quarry and cement plant facili-

*All mine numbers in this section refer to "Active Mines" on the location map and in Table 1.

Bristol Silica and Limestone Company's mine in Jackson County. Open-pit quarry in background, crusher and screening plant in foreground. Here, silica rock used for decorative granules and silicon metal is produced.



EXPLANATION

ACTIVE MINES (half-filled square)

1. Tempest (Ag)
2. Pyx (Au)
3. Boulder Creek (Au)
4. Elk Heaven (Au, Ag)
5. Thomason (Au)
6. Burnt River (Au)
7. Pine Creek (Au)
8. Clarks Creek (Au)
9. Ash Grove Cement West (cement, limestone)
10. Teague Mineral Products (bentonite, zeolite)
11. Fall Creek Gold (Au)
12. Josephine Creek and tributaries (Au)
13. Sucker Creek (Au)
14. Althouse Creek (Au)
15. Galice area placers (Au)
16. Greenback (Au)
17. Nickel Mountain (Ni)
18. Coffee Creek (Au)
19. Quartz Mountain Silica (silica)
20. Bristol Silica (silica)
21. Steatite of Southern Oregon (soapstone)
22. Cascade Pumice, Central Oregon Pumice (pumice)
23. Camp Creek (clay)
24. Oil-Dri West (diatomite)

EXPLORATION SITES AND AREAS (solid triangle)

1. Rejax (Au, Ag)
2. Bear Creek Buttes (Au)
3. Miller Mountain (Au)
4. Susanville (Au, Ag)
5. Dixie Meadows (Au, Ag)
6. Bald Mountain-Ibex (Au, Ag)
7. Cable Cove (Au, Ag)
8. Meadow Lake (Au, Ag)
9. Grouse Spring (Cu, Mo)
10. Flagstaff (Au)
11. Iron Dyke (Au, Ag, Cu)
12. Dooley Mountain (perlite)
13. Turner-Albright (Au, Ag, Zn, Cu, Co)
14. Fall Creek Copper (Au, Ag, Cu, Co)
15. Gold Bug (Au)
16. Goff (Au, Ag, Cu, Pb, Zn)
17. John Hall (Au)
18. Gold Note (Au, Ag, Cu)
19. Foster Creek (clay)
20. Quartz Mountain (Au)
21. Little Baldy (Au)
22. Tucker Hill (perlite)
23. Coyote Hills (Au)
24. Harney prospect (zeolite)
25. Flagstaff Butte (Au)
26. Celatom (diatomite)
27. Castle Rock (Au)
28. Sunday Hill (Au)
29. Red Butte (Au)
30. Rome prospect (zeolite)

Mining and mineral exploration in Oregon in 1985 (excluding sand and gravel and stone). Active mines are keyed to Table 1; exploration sites are keyed to Table 2.

ties near Durkee in southern Baker County. The plant at Durkee was built in 1980 and has an annual production capacity of 500,000 tons of cement. Additional amounts of crushed limestone from the quarry are supplied to sugar manufacturing plants in Idaho.

The new management at Bristol Silica and Limestone Company (20) continued to produce metallurgical-grade silica rock for Dow Corning at its mine in Jackson County. Other products included poultry grit and fine-grained silica used for filtration. Silica production was down from the previous year, and no limestone or dolomite was shipped from the property in 1985.

Hanna Mining Company continued to utilize silica rock from the Quartz Mountain Silica Mine (19) in eastern Douglas County in its nickel smelter. Production was lower than in 1984 due to the smelter shutdown during construction of the new wet-screening plant.

Steatite of Southern Oregon (21) produced block soapstone suitable for carving from its mine on Elliot Creek Ridge in southern Jackson County. Shipments of block soapstone reportedly declined slightly in 1985.

The Oregon Sun Ranch and Central Oregon Bentonite clay pits on Camp Creek (23) in central Oregon were active producers in 1985. Both properties produce low-grade clays that are used primarily in the cat-litter industry.

Teague Minerals Products (10) continued to produce bentonitic clay and zeolite from its pits near Adrian in eastern Malheur County.

Table 1. *Active mines in Oregon, 1985*

Map no.	Name	Location	Commodity	Comments
1.	Tempest	Sec. 10 T. 9 S., R. 34 E. Grant County	Ag	Newly erected small mill produced small amount of concentrates.
2.	Pyx	Sec. 1 T. 10 S., R. 35 E. Grant County	Au	Continued small, seasonal production.
3.	Boulder Creek	Sec. 34 T. 8 S., R. 35½ E. Grant County	Au	Small placer operation.
4.	Elk Haven	Sec. 16 T. 8 S., R. 36 E. Grant County	Au, Ag	Produced small amount of concentrates.
5.	Thomason	Sec. 6 T. 14 S., R. 37 E. Baker County	Au	Continued small, seasonal operation.
6.	Burnt River	T. 10 S., Rs. 35, 35½ E. Baker County	Au	Several small placer operators.
7.	Pine Creek	T. 12 S., R. 39 E. Baker County	Au	Several small placer operators.
8.	Clarks Creek	Tps. 12, 13 S., R. 41 E. Baker County	Au	Several small placer operators.
9.	Ash Grove Cement West	Sec. 11 T. 12 S., R. 43 E. Baker County	Cement, limestone	Continued production.
10.	Teague Mineral Products	Sec. 29 T. 23 S., R. 46 E. Malheur County	Bentonite, zeolite	Continued production.
11.	Fall Creek Gold	T. 38 S., R. 9 W. Josephine County	Au	Small production from placer and lode by owner Tim Von Pinnon.
12.	Josephine Creek & tributaries	Secs. 30, 36 T. 38 S., Rs. 8, 9 W. Secs, 2, 11 T. 39 S., R. 8 W. Josephine County	Au	Several small placer operators.

Table 1. *Active mines in Oregon, 1985 — continued*

Map no.	Name	Location	Commodity	Comments
13.	Sucker Creek	Sec. 1 T. 40 S., R. 7 W. Josephine County	Au	Several small placer operators.
14.	Althouse Creek	Secs. 11, 12 T. 41 S., R. 7 W. Josephine County	Au	Several small placer operators.
15.	Galice area (Galice Creek, Taylor Creek, Rocky Gulch)	Secs. 25, 36 T. 34 S., R. 8 W. Secs. 2, 10, 16 T. 35 S., R. 8 W. Josephine County	Au	Several small placer operators.
16.	Greenback	Secs. 32, 33 T. 33 S., R. 5 W. Sec. 5 T. 34 S., R. 5 W. Josephine County	Au	Property returned to owners, Sunny Valley Mining & Development Co., who are currently mining on the Irish Girl vein.
17.	Nickel Mountain	Sec. 17 T. 30 S., R. 6 W. Douglas County	Ni	Mine and smelter reopened in November after installing new wet-screening plant.
18.	Coffe Creek	Sec. 7 T. 30 S., R. 2 W. Douglas County	Au	Small placer operation.
19.	Quartz Mountain Silica	Sec. 2 T. 28 S., R. 1 E. Douglas County	Silica	Reduced production due to smelter shutdown.
20.	Bristol Silica	Sec. 30 T. 36 S., R. 3 W. Jackson County	Silica	Silica production reduced from 1984 level.
21.	Steatite of Southern Oregon	Secs. 10, 11 T. 36 S., R. 3 W. Jackson County	Soapstone	Production of carving-grade soapstone declined from 1984 level.
22.	Cascade Pumice, Central Oregon Pumice	Bend area Deschutes County	Pumice	Continued production.
23.	Camp Creek	T. 19 S., R. 21 E. Crook County	Clay	Oregon Sun Ranch, Inc., and Central Oregon Bentonite Co. producing clays.
24.	Oil-Dri West	T. 27 S., R. 17 E. Lake County	Diatomite	Continued production of diatomite used mainly in pet litter.

OREGON'S MINERAL PRODUCTION
MILLIONS OF DOLLARS

	ROCK MATERIALS Sand & Gravel, Stone	METALS & INDUSTRIAL MINERALS Cement, Nickel, Pumice, etc.	NATURAL GAS	TOTAL
1972	54	22	0	76
1973	55	26	0	81
1974	75	29	0	104
1975	73	33	0	106
1976	77	35	0	112
1977	74	35	0	109
1978	84	44	0	128
1979	111	54	+	165
1980	95	65	12	172
1981	85	65	13	163
1982	73	37	10	120
1983	82	41	10	133
1984	75	46	8	129
1985	78	39	10	127

Summary of mineral production in Oregon for the last 16 years. Data for 1985 derived from U.S. Bureau of Mines annual preliminary Mineral Industry Survey and Oregon Department of Geology and Mineral Industries natural gas production statistics.

EXPLORATION AND DEVELOPMENT ACTIVITY

The level of mineral exploration and development activity in 1985 generally declined from 1984 levels. Industry interests continued an ongoing shift in emphasis from metallic to nonmetallic commodities.

Metals

State and Federal research teams continued their search for submarine polymetallic sulfide deposits along the Juan de Fuca and Gorda Ridges off the Oregon coast. The Oregon Department of Geology and Mineral Industries released a comprehensive map (GMS-37) showing known offshore mineral resources.

Similar onshore polymetallic sulfide deposits continued to be evaluated in southwest Oregon. The Turner Albright Mine (13)** in extreme southwest Josephine County is one of the best known sulfide deposits in Oregon. The property is now owned by Baretta and is currently being evaluated by Ray Rock Mines, Inc. Ray Rock did a pulse-electromagnetic geophysical survey to determine the downdip extension of the ore zone.

Previous drilling programs by Baretta and Noranda reportedly outlined 3.3 million tons of reserves averaging 0.114 oz per ton of gold, 0.443 oz per ton of silver, 1.46 percent copper, 3.32 percent zinc, and 0.055 percent cobalt.

Ore-dressing research on the complex sulfide ore is being conducted by the U.S. Bureau of Mines (USBM) research center in Salt Lake City, Utah.

The U.S. Geological Survey (USGS) is also conducting a study of the deposit as an onshore example of a submarine black-smoker deposit.

Seneca Exploration of Vancouver, B.C., and Litho-Logic Resources of Grants Pass, Oregon, are conducting a geologic mapping and sampling program on the Fall Creek Copper (14) massive sulfide deposit in Josephine County. The deposit is situated about 10 mi west of Selma along Fall Creek, a tributary of the Illinois River. The massive sulfide deposit is associated with pillow basalts and ultramafic rocks and may be another example of a black-smoker deposit.

Other massive sulfide deposits currently being evaluated in Oregon are hosted by island-arc volcanic rocks. Amselco is conducting a drilling project on one of these deposits, the Goff Mine (16), located in Josephine County about 2 mi north of Grave Creek between Rock Creek and Reuben Creek. The deposit is in siliceous tuffs and contains massive sulfides capped by barite. Amselco is drilling on lands leased for exploration from Josephine County.

**All site numbers in this section refer to "Exploration Sites and Areas" on the location map and in Table 2.

Boise Cascade drilled the Gold Note (18) stratabound sulfide deposit on the Josephine-Jackson County line in the upper Grave Creek area.

Activity on similar deposits in northeastern Oregon has been steadily decreasing in recent years. The Iron Dyke Mine (11) on the Snake River in eastern Baker County was inactive through most of 1985. The owner and operator, Silver King Mines, Inc., placed a crew on the property in late fall of 1985 with the expressed intent of mining out a 20,000-ton ore body left from earlier operations. The ore body is reported to run about 0.3 oz per ton of gold and 3 percent copper.

Most of the recent activity in northeast Oregon has focused on vein gold deposits about the margins of the Late Jurassic-Early Cretaceous intrusions. During spring, Rio Algom put down some drill holes on the Sunday Hill Mine (28) located in the old Mormon Basin district in southern Baker County. The property is held by Capri Resources Ltd. of Vancouver, B.C.

Sunshine Mining and Minerals was active in the Virtue Flat district east of Baker. The company sampled some of the accessible underground workings on the old Flagstaff Mine (10). This property explored quartz veins and sheared gouge zones in a metamorphosed intrusive complex of gabbro and quartz diorite.

Inspiration drilled 12 holes at the Dixie Meadows Mine (5) north of Prairie City. Drill results were discouraging, and Inspiration dropped its option on the property which is held by Big Turtle Mines, Inc., of Boise, Idaho.

American Copper and Nickel Company, Inc., a subsidiary of INCO Ltd., continued exploration at its Susanville property (4) in northern Grant County. The property is located adjacent to the southwest margin of the Sunrise Butte stock and contains several sulfide-rich precious metal veins that are hosted in schist and serpentine. In 1985, American Copper and Nickel continued evaluation of one of those, the Bull of the Woods vein, in a 6,000-ft surface-drilling program.

American Copper and Nickel was also active in and along the margins of the Bald Mountain Batholith. This area has historically been one of the most productive lode gold regions in Oregon. American Copper and Nickel continued its evaluation of the Bald Mountain Mine (6) under the terms of a joint venture agreement with the owners of the property, Ibex Mining Company. The 1985 program consisted of a 9,500-ft surface drilling program on the Bald Mountain-Ibex and Grand Trunk vein systems. The drill program was completed in late November. Other lode properties along the southern margins of the batholith, including the North Pole-Columbia, Cougar-Independence, Buffalo, and Argonaut Mines, were idle in 1985.

Table 2. *Exploration sites and areas in Oregon, 1985*

Map no.	Name	Location	Commodity	Comments
1.	Rejax	SE part of T. 9 S., R. 17 E. Jefferson County	Au, Ag	Continued exploration by Ocelot Industries Ltd.
2.	Bear Creek Buttes	T. 18 S., R. 17 E. Crook County	Au	Exploration program by Shell Mining Company.
3.	Miller Mountain	Sec. 22 T. 14 S., R. 32 E. Grant County	Au	Sampling of underground workings by CBM.
4.	Susanville	T. 10 S., R. 33 E. Grant County	Au, Ag	Continued diamond drill program by American Copper and Nickel.
5.	Dixie MeadowsSec. 23 T. 11 S., R. 33 E. Grant County	Au, Ag	Drill program by Inspiration.	
6.	Bald Mountain-Ibex	Sec. 4 T. 9 S., R. 36 E. Baker, Grant Counties	Au, Ag	Continued diamond drill program by American Copper and Nickel.

Table 2. *Exploration sites and areas in Oregon, 1985 —continued*

Map no.	Name	Location	Commodity	Comments
7.	Cable Cove	T. 8 S., R. 36 E. Baker County	Au, Ag	Small drill program by American Copper and Nickel.
8.	Meadow Lake	T. 8 S., R. 37 E. Baker, Grant Counties	Au, Ag	Shell Mining Company joined in joint venture program with Manville Corp.
9.	Grouse Spring	Secs. 24, 25 T. 14 S., R. 36 E. Baker County	Cu, Mo	Small drill program by Manville Corp.
10.	Flagstaff	Sec. 5 T. 9 S., R. 41 E. Baker County	Au	Underground workings sampled by Sunshine.
11.	Iron Dyke	Sec. 21 T. 13 S., R. 45 E. Baker County	Au, Ag, Cu	Reopened by Silver King.
12.	Dooley Mountain	Tps. 11, 12 S., R. 40 E. Baker County	Perlite	Evaluation program by Supreme Perlite.
13.	Turner-Albright	Secs. 3, 15, 16 T. 41 S., R. 9 W. Josephine County	Au, Ag, Zn, Cu, Co	Continued evaluation by Ray Rock.
14.	Fall Creek Copper	Tps. 37, 38 S., R. 9 W. Josephine County	Au, Ag, Cu, Co	Mapping and sampling program by Seneca Exploration and Litho-Logic Resources.
15.	Gold Bug	Sec. 26 T. 33 S., R. 8 W. Josephine County	Au	Old workings reopened by GeoMining Company of Salt Lake City.
16.	Goff	Secs. 20, 29 T. 33 S., R. 7 W. Josephine County	Au, Ag, Cu, Pb, Zn	Drill program by Amselco.
17.	John Hall	Sec. 18 T. 34 S., R. 5 W. Josephine County	Au	David Gaunt and Gene Lattimer of Sunny Valley reopened old workings and set up small mill.
18.	Gold Note	Sec. 30 T. 33 S., R. 3 W. Jackson, Josephine Counties	Au, Ag, Cu	Drill program by Boise Cascade.
19.	Foster Creek	T. 29 S., R. 3 E. Douglas County	Clay	Evaluation of soil amendment material by Cascade Sulfur Company.
20.	Quartz Mountain	T. 37 S., R. 11 E. Lake County	Au	Continued evaluation of large-tonnage epithermal gold deposit.
21.	Little Baldy	T. 34 S., R. 16 E. Lake County	Au	Exploration program by Long Lac.
22.	Tucker Hill	Sec. 35 T. 34 S., R. 19 E. Lake County	Perlite	Continued evaluation by Tenneco.
23.	Coyote Hills	T. 35 S., R. 23 E. Lake County	Au	Drilled and later dropped by Cominco American.
24.	Harney prospect	T. 27 S., R. 31 E. Harney County	Zeolite	Continued drilling by Anaconda.
25.	Flagstaff Butte	T. 39 S., R. 37 E. Harney County	Au	Exploration program by Utah International.
26.	Celatom	Tps. 19, 25 S., Rs. 35, 36, 37 E. Harney, Malheur Counties	Diatomite	Plant construction by Eagle Picher.
27.	Castle Rock	T. 18 S., R. 37 E. Malheur County	Au	Exploration program by Manville Corp.
28.	Sunday Hill	Sec. 17 T. 13 S., R. 42 E. Malheur County	Au	Drilled by Rio Algom.
29.	Red Butte	Secs. 26, 27, 34, 35 T. 25 S., R. 43 E. Malheur County	Au	Tenneco joint-ventured with Manville Corp. on a sampling and mapping program.
30.	Rome prospect	Tps. 31, 32 S., R. 41 E. Malheur County	Zeolite	Continued drilling by Anaconda.

New wet-screening plant at Hanna Nickel Company high on the flanks of Nickel Mountain. Here, nickel-bearing, fine, weathered material is separated from unweathered rock and transported down the mountain as a slurry.

American Copper and Nickel completed a 1,600-ft surface-drilling program in the heart of the Cable Cove (7) district within the batholith. The veins here consist of brecciated granodiorite that has been locally altered to clay minerals and sericite and impregnated with lenses and streaks of quartz, calcite, and sulfide minerals. The sulfide lenses, which may contain appreciable amounts of gold and silver, consist primarily of pyrite and arsenopyrite, with accessory galena, sphalerite, chalcopyrite, and occasional molybdenite and stibnite.

Shell Mining Company became a joint venture partner on the Meadow Lake property (8) owned by Manville. The property, which is located along strike to the northeast of the Cable Cove veins, had been previously evaluated by Manville for copper-molybdenum mineralization. Last summer's joint venture project consisted of mapping and sampling of associated precious metal mineralization.

Other porphyry deposits of consequence include the Cedar Creek prospect in the Quartzville district in the Western Cascades, which is held by Amoco, and the Grouse Springs prospect in southern Baker County, which is held by Manville. Manville continued its small-scale surface-drilling program on the property this past summer.

Zones of precious-metal mineralization hosted in Tertiary volcanic and sedimentary rocks continued to be popular exploration targets in 1985. A number of companies conducted exploration and evaluation programs in the Western Cascade, Ochoco, Quartz Mountain, McDermitt, and Vale-Weiser areas.

Tenneco began an extensive surface sampling and mapping program at Manville's Red Butte (29) property in central Malheur County. This is a presumably caldera-associated deposit of the hot-springs type, hosted in tuffaceous sedimentary rocks of Miocene age.

Manville continued its surface sampling and mapping program on its Castle Rock property (27) in northern Malheur County. Precious metal mineralization there is reported to occur in the Miocene rhyolite flow-dome complex.

Cominco-American drilled nine reverse-circulation holes at Coyote Hills (23) in central Lake County. Stockworks of quartz-pyrite mineralization are reported to occur along northwest-trending fracture zones at and near intersecting northeast-trending fractures. In fall of 1985, the property, which is presumably located in a late Tertiary volcanic complex, was dropped by Cominco-American due to discouraging drill results.

Evaluation of the Quartz Mountain (20) property northwest of Lakeview in Lake County continued through 1985. The property was held in a joint venture agreement between Anaconda and Exploration Ventures of Spokane, Washington. Gold mineralization on the 3,200-acre property is reportedly associated with late Tertiary rhyolite porphyry intrusions that cut the Miocene tuffaceous sedimentary rocks. The main defined mineralized zone at Krone Hill is centered on an alteration zone adjacent to one of four intrusions on the property. Better grade gold mineralization is said to be present in a stratabound replacement zone located along the margins of the rhyolite porphyry. The zone locally contains high-grade veins, stockworks, and hydrothermal breccias. Gold mineralization is also known to occur in a contact breccia and in a hot springs sinter deposit. Based on 11,525 ft of drilling done earlier on 32 holes by Anaconda, a potential resource of 25 million tons of rock grading better than 0.04 oz per ton of gold has been identified on the property. Anaconda's interest in the property was transferred to a Vancouver, B.C., company in 1985 as part of the Anaconda breakup.

Nonmetals

The year 1985 saw increased activity in exploration and development of nonmetallic mineral resources. The Celatom diatomite project (26), owned and operated by Eagle Picher Industries, Inc., continued toward production. Four mine sites on the 3,700-acre property, located along the Malheur-Harney County line near Drewsey, are expected to provide 140,000 yd^3 of diatomite ore per year. The ore will be shipped to a processing plant now being constructed 7 mi west of Vale in Malheur County. The $13-million project is partially funded by an Industrial Revenue Bond and an Urban Development Action Grant. The processing plant is expected to be completed in the summer of 1986, at which time diatomite ore mined this past summer will be processed.

Geologists for Tenneco Minerals Company reported in 1985 that the Tucker Hill perlite deposit (22) in Lake County contained resources of at least 20 to 40 million tons of vesicular to granular perlite and perlite breccias amenable to open-pit mining. Bulk sample tests made by Tenneco suggest that the perlite is suitable for a number of industrial applications including horticultural and loose-fill insulation products as well as the production of insulation board and acoustical tile. Feasibility studies continued in 1985.

Supreme Perlite, a Portland-based company, continued its evaluation of the perlite deposits at Dooley Mountain (12) in southern Baker County. The Miocene rhyolite center at Dooley Mountain is currently being mapped in detail by the U.S. Geological Survey.

Several companies continued to evaluate zeolite prospects. Anaconda conducted an assessment drilling program on its Harney property (24) south of Burns in Lake County. This is reportedly one of the largest clinoptilolite deposits in the world, partially replacing a 215-ft-thick ash flow tuff. Anaconda indicates that the deposit may contain around 1 billion tons of 90 percent clinoptilolite rock.

Anaconda also continued its drilling program at Rome (30) in Malheur County. The zeolite resource here has been reported as 30 million tons of 60 percent mordenite.

Cascade Sulfur Company has been conducting an exploration of soil amendment material mined from an area of hydrothermal alteration of dacitic volcanic rocks in the Foster Creek (19) drainage of southeastern Douglas County. The material reportedly contains in large part bentonitic clays (montmorillonite) with some pyrophyllite, fine disseminated pyrite, and secondary sulfates. Test results on application to both alkaline and acid soils appear to be very encouraging. More than 1,000 tons of material have been mined and applied to various sites including Klamath and Lake County alfalfa fields and the U.S. Bureau of Land Management tree plantation near Provolt. The company plans further testing and development of its deposit. □

A reinterpretation of the Gray Butte limestone and arenite exposure as a hydrothermally-derived calcite vein and pebble dike

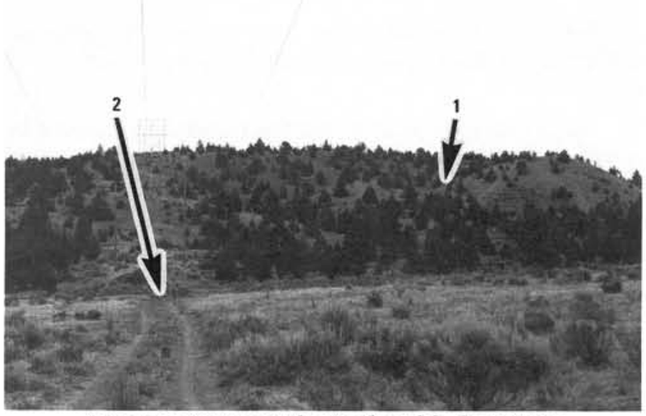
by Jerry J. Gray and Gary Baxter, Oregon Department of Geology and Mineral Industries

In the July 1979 issue of *Oregon Geology*, Ashwill, in a reconnaissance study, locates and describes "limestone" occurring on the western flank of Gray Butte, Jefferson County. The main outcrop is located approximately 15 mi south of Madras in the SE¼ SE¼ sec. 22, T. 13 S., R. 13 E., and a second exposure lies about 100 yd west of the first (Ashwill, 1979). Other rocks cropping out nearby are described as "arenite." Both the "limestone" and "arenite" are assumed to be sedimentary in origin. The "arenites" and other clastic rocks are described as older than the surrounding rocks because of their "anomalously steep dips, indications of metamorphism in the recrystallization of the limestone, and the quartzic arenites."

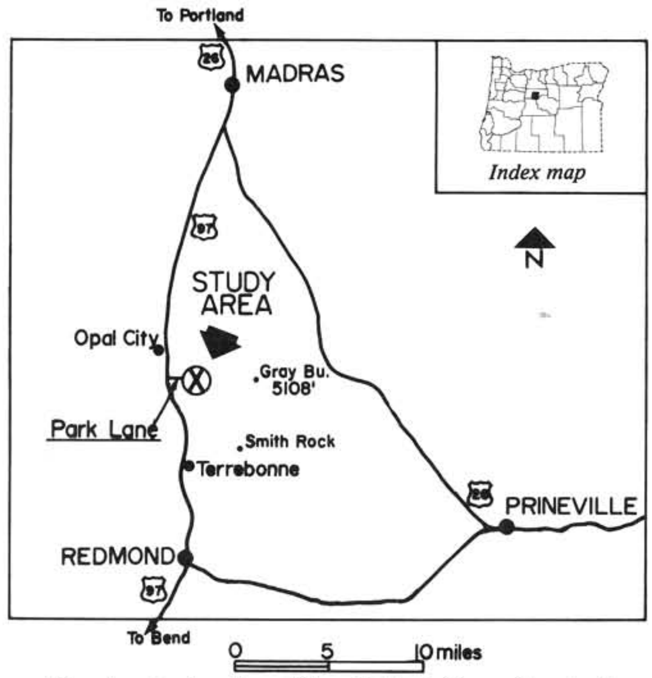
The authors suggest that the "limestone" and "arenite" are not sedimentary in origin. The "limestone" instead appears to be a calcite vein and the "arenite" a pebble dike (breccia formed by hydrofracturing occurring during hydrothermal activity) that are both part of a hot-spring system. While conducting Oregon Department of Geology and Mineral Industries (DOGAMI) geochemical studies of hydrothermal systems, the first author visited the Gray Butte "limestone/arenite" area during the 1984 field season and collected several samples for assaying and petrographic study. All the samples that were assayed had detectable gold, two showed anomalous values for arsenic, one had anomalous silver values, and one had anomalous mercury values (Table 1). Thin sections were cut from three of the samples that had been collected for petrographic study. Two of these three samples were also examined by X-ray diffraction. The assay, X-ray, and petrographic data and the authors' interpretation are given in Table 1.

Three other factors should be noted. The first is that 2 mi northwest of the "limestone/arenite," the Gray Butte mercury prospect occurs. Brooks (1963) describes the geology and mineralization of this prospect as follows:

"Cinnabar is sparsely distributed along an east-trending zone of faulting which can be traced for about 1,000 ft. At the west end of the area, the fault zone is expressed by a rib of silicified tuff from 2 to 6 ft wide protruding in places as much as 8 ft above the surface. The rib is bordered on the north by a 2-ft-wide zone of mildly silicified gouge and brecciated tuffs. Cinnabar is visible as fracture coatings along the north edge of the silicified rib."

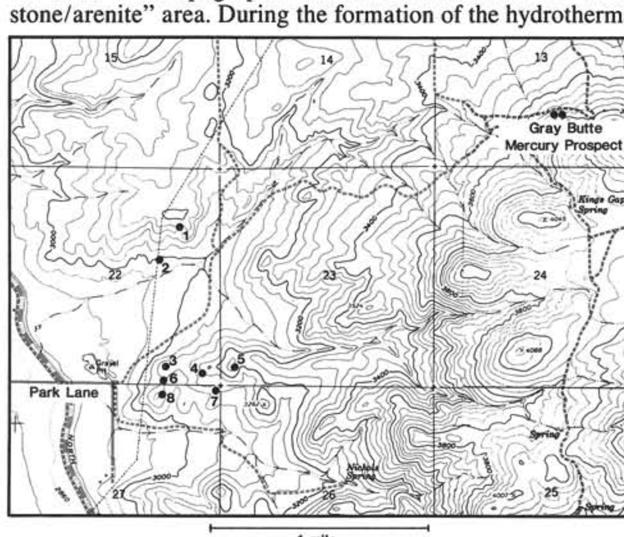


Arrows point to sample sites 1 and 2, Gray Butte.



Map showing location of Gray Butte, Jefferson County, Oregon. Park Lane leads to study area that is shown in greater detail on map below.

The second factor is inferred from the topographic map of the area. Two topographic lows almost surround the "limestone/arenite" area. During the formation of the hydrothermal



Partial topographic map of T. 13 S., R. 13 E. showing locations from which samples were collected for this study.

Table 1. *Assay data and petrology, Gray Butte, Jefferson County, Oregon*

	Assays (ppm)								Mineralogical analysis technique		
Sample no.	Au	Ag	As	Cu	Hg	Mo	Pb	Zn	Thin section (?)	Clay fraction X-ray (?)	Rock name
1	0.003	*0.93	4	10	0.08	4.8	9	68	Yes	No	Jasperoid
2	0.002	0.16	3	9	0.04	3.3	15	83	No	No	Jasperoid
3	0.007	0.10	*15	51	*1.30	2.2	4	50	No	No	Breccia
4	---	---	---	---	---	---	---	---	No	No	Calcite
5	0.003	0.11	*14	48	0.24	4.1	4	71	No	No	Breccia
6	---	---	---	---	---	---	---	---	Yes	Yes	Breccia
7	0.003	0.12	4	52	0.07	0.7	5	79	Yes	Yes	Breccia
8	0.003	0.06	3	90	0.08	0.6	2	71	No	No	Andesite (?)

*Anomalous value.

Comments on samples in Table 1:

1. Sample taken from an outcrop 200 ft long and several feet thick. The rock, which has yellow, brown, and green patterns, is being mined by rockhounds as picture rock. Thin-section examination indicates that this rock is a silicified ash-fall tuff that formed from air fall of ash into a quiet body of water.
2. Lake-bed sediments that have been silicified. Some secondary fracturing and silicification have occurred. The rock is tan, and the secondary silicification is green. The outcrop is 100 ft by 50 ft by 20 ft and is being used as the footing for a power-line tower.
3. Silicified, brecciated, and mineralized sample. The rock has slickensides, indicating movement has occurred after silicification.
4. Coarse crystalline calcite that is white on a fresh surface. No assays were performed.
5. Silicified, brecciated, mineralized rock that is impregnated with calcite. The outcrop is at least a couple of hundred of feet square.
6. "Arenite," as mapped by Ashweill. Outcrop was extended farther to the west by 1984 DOGAMI field work. Sample 6 was taken from the west end of the "arenite," and sample 7 was taken from the east of the center of the outcrop. The sample-6 thin section shows that the "arenite" sand grains are rounded breccia fragments of mostly jasperoids after tuffs. The spaces between the fragments are filled with quartz, calcite, and clay minerals. X-ray diffraction indicates that the clay minerals are chlorite and kaolinite. The outcrop is probably a pebble dike caused by steam explosions.
7. "Arenite" sample similar to sample 6, except that X-ray shows that the clay mineral illite (a higher temperature clay) is also present.
8. Sample field identified by the authors as andesite. It is calcite bearing and carries detectable gold. No thin sections were prepared from this sample.

Closeup of sample site 1, showing pit where silicified lake-bed sediments have been mined by rockhounds for picture rock.

Sample site 7, a pebble dike probably caused by hydrofracturing of rock by steam explosions during hot-spring activity.

(hot spring), silica-rich systems, a clay alteration zone may form around the area of silicification. This may be the reason for the two topographic lows.

The third factor is that nearby lakebed sediments from which fossils have been reported (Ashwill, 1983) have been silicified —a sign of hot springs activity.

In summary, the rock types, silicification, brecciation, calcite veining, gold and other metal mineralization, topography, and the nearby mercury prospect all suggest a hydrothermal system in the Gray Butte area. Detailed geologic mapping, geochemical surveying, and drilling will be needed to determine if this and nearby areas have potential for being a commercial gold deposit.

The petrographic samples and thin sections are available for study at the Portland office of the Oregon Department of Geology and Mineral Industries.

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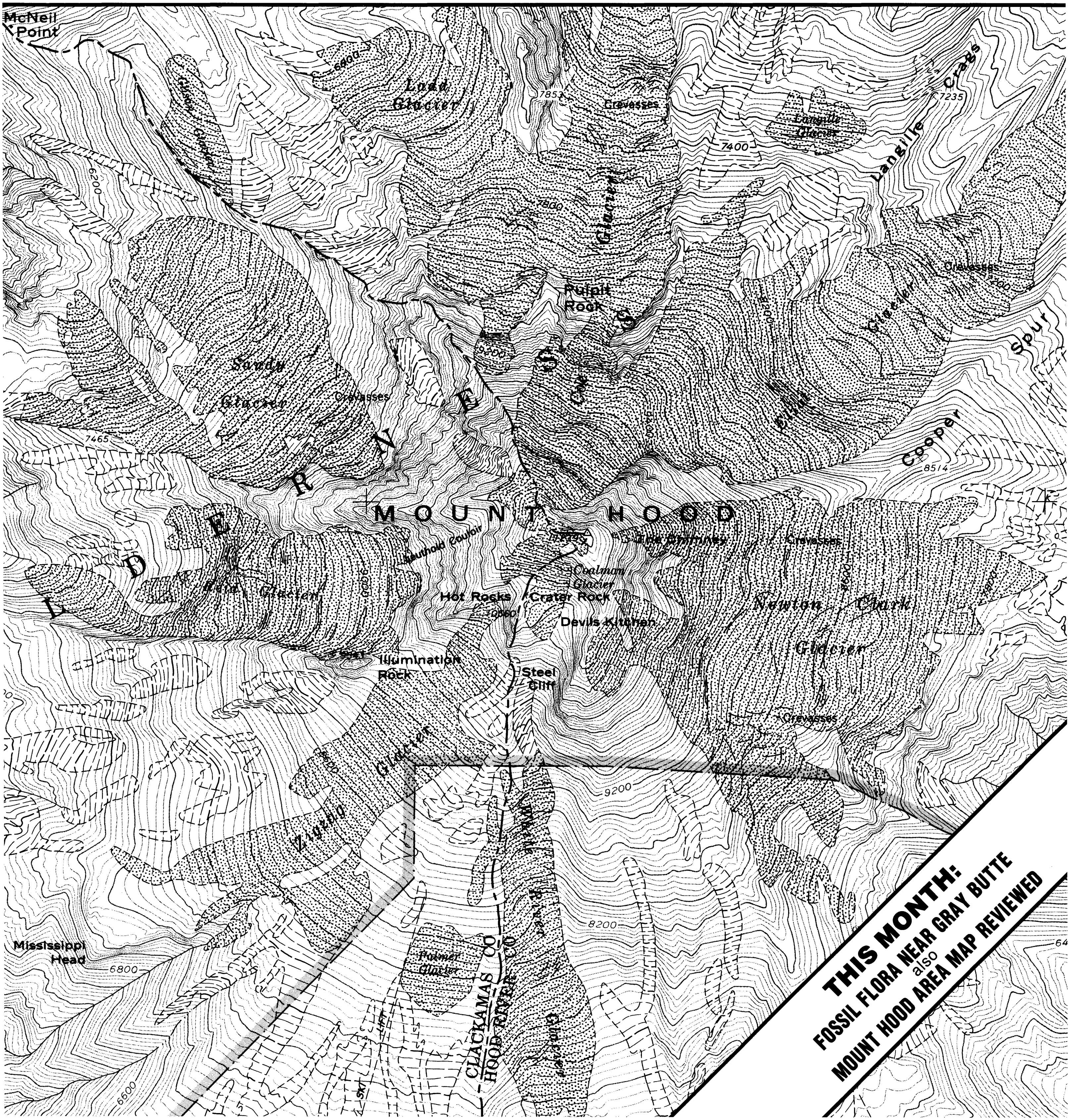

THIS MONTH:
FOSSIL FLORA NEAR GRAY BUTTE
also
MOUNT HOOD AREA MAP REVIEWED

OREGON GEOLOGY
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COVER PHOTO

Central portion of topographic map showing the Mount Hood, Oregon, volcano area, actual size. The map is described in review on page 58.

OIL AND GAS NEWS

NWPA to hold annual symposium

The Northwest Petroleum Association has scheduled its third annual symposium and field trip for May 15-16 in Olympia, Washington. The meeting, to be held at the Olympia Westwater Inn, will feature several speakers from government and industry, and the field trip will include the Centralia Coal Plant, Satsop Nuclear Plant, and stops to see the Lincoln Creek and Astoria Formations. Details are available from Barbara Portwood, (503) 287-2762.

Columbia County to hold lease sale

June 11 is the date set by the Columbia County Board of Commissioners for its next oil and gas lease sale. The sale, to be held in the Old Courthouse, First Street, St. Helens, Oregon, will start at 10 a.m. and will offer 68,000 acres for lease. The lease term is 10 years with a 3/16 royalty. Additional information is available from the Board of Commissioners, (503) 397-4322.

Gas storage project clears dispute

Oregon Natural Gas Development Corporation (ONGD) plans to convert to gas storage two depleted pools in the Mist Gas Field. An agreement has been reached out of court between the company and Columbia County over the County's interest in the Bruer and Flora pools. ONGD will pay Columbia County $550,000 for mineral interests in the proposed storage pools, covering an area of 940 acres and extending to the base of the pools.

The settlement to the county will be shared among the local taxing districts. A specific value was not determined for the remaining gas in place. The operator will now move forward with plans for several injection-withdrawal wells into the pools for possible gas storage in 1987.

MMS hearing on offshore 5-year oil and gas plan

The Mineral Management Service (MMS) has released the Draft Environmental Impact Statement for the Proposed 5-Year Outer Continental Shelf (OCS) Oil and Gas Leasing Program January 1987-December 1991 and held three public hearings in April to receive comments on the draft. At the April 10 hearing in Portland, nine persons testified in favor of leasing the OCS, while four opposed leasing. Various suggestions were made on how to modify the proposed program. Arguments in favor of leasing included meeting energy needs, reducing foreign imports, and supplying jobs, while statements against the leasing schedule centered on damage to the environment, the need for more base-line scientific studies on the OCS, and the low potential for hydrocarbons off Oregon and Washington. The next step in the process is the writing of a Final Environmental Impact Statement in early 1987. □

Roberts, King retire from DOGAMI

Two staff members of the Oregon Department of Geology and Mineral Industries have recently left the Department to enjoy their well-earned retirement: June Roberts, Administrative Assistant, had served the Department for over 45 years. She lives in Portland. William L. King joined the Department in 1981 as Petroleum Geologist to work on the growing task of oil and gas development and regulation. He currently resides in Beaverton. □

Fossil flora near Gray Butte, Jefferson County, Oregon

by Jerome J. McFadden, former Camp Hancock student, 411 S. Morain St., Kennewick, Washington 99336

ABSTRACT

Fossils of the Sumner Spring flora found at Gray Butte in Jefferson County, Oregon, indicate a temperate climate. Although occurring in an area previously mapped as Eocene Clarno Formation (Robinson and Stensland, 1979), the low diversity and species composition of the Sumner Spring floral assemblage suggest closer similarity to the known Oligocene floras of the John Day Formation.

INTRODUCTION

Gray Butte is a prominent feature rising to an elevation of 1,557 m above the Crooked River flood plain in Jefferson County. It is located about 4 mi northeast of Smith Rock State Park and 15 mi south of Madras. Fossil plants have been collected from the surrounding area since the 1930's (Vance, 1936). Collections of Gray Butte fossils are housed at the Oregon Museum of Science and Industry (OMSI) in Portland and the Museum of Paleontology, University of California at Berkeley, as well as in a number of private collections. The source locality of these fossils has not been published or recorded with the museum collections.

Renewed field work in the area has resulted in the discovery of several fossil plant localities on the flanks of Gray Butte and the rediscovery of the original diggings referred to by Vance (1936). Ashwill (1983) published a preliminary account of each of the Gray Butte assemblages and called attention to their varying floral compositions. He recognized three distinct assemblages, which he named the Nichols Spring, Sumner Spring, and Canal floras. This report focuses on the Sumner Spring fossil flora of Gray Butte, in an effort (1) to clarify its floral composition, the age of the flora, and the formation to which it belongs, and (2) to determine the climatic conditions during its deposition.

SUMNER SPRING FLORA

Two main outcrops containing the Sumner Spring flora are discussed in this study. The first, OMSI locality 78, represents the original collection site of A.W. Hancock and R.W. Chaney, which was mentioned by Vance (1936) and rediscovered by M. Ashwill and S. Manchester in 1980. It is situated in NE¼ NE¼ sec. 26, T. 13 S., R. 13 E., Opal City quadrangle. The matrix is gray-green, very hard shale. The strata are covered with top soil except in shallow collection pits. Fossils are not abundant and require much effort to extract.

The second outcrop, OMSI locality 75, is situated half a mile east of locality 78 in SW¼ SE¼ sec. 24 and in adjacent NE¼ NW¼ sec. 25, T. 13 S., R. 13 E., Gray Butte quadrangle. This site was discovered by Ashwill in 1979. Fossils were collected south of the power line on the south-facing slope of a knoll adjacent to Gray Butte. Most of this author's collecting was in the weathered surface shales and slump blocks not exceeding 1 m in diameter. Collections were also taken from a stream-bed exposure at the southern base of the knoll. Collecting, erosion, and slumping have all but obliterated this stream-bed exposure. Although no exposed contacts between the fossiliferous sediments and the overlying and underlying strata were found, the vertical thickness of the fossiliferous sediments appears to be at least 15 m. Matrix from the site ranges from pale yellow to green. Surface shales are highly fractured. Larger blocks are well indurated and sometimes brittle. OMSI locality 75 underlies a basalt flow that caps the knoll.

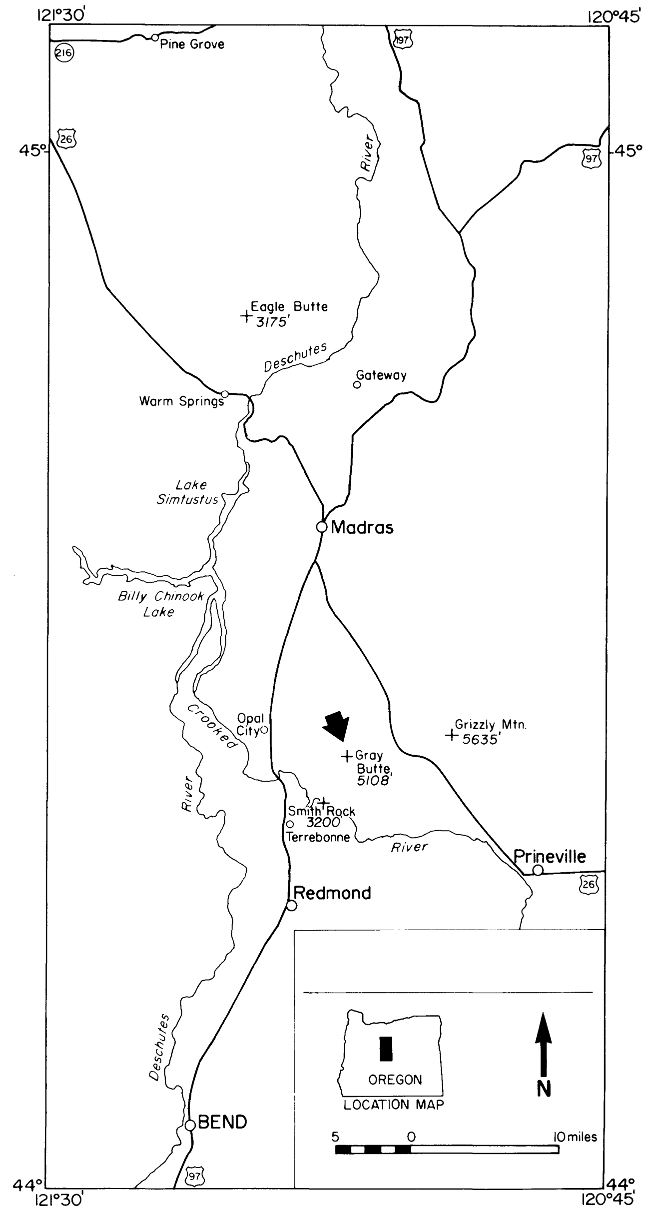

Figure 1. Map showing locality of Gray Butte, Jefferson County, Oregon.

Studies of the fossil flora composition are based on collections made by the OMSI summer paleoecology teams of 1980 and 1981, Melvin Ashwill, and the author. The sum of these collections exceeds 250 specimens. All specimens figured in this paper are housed in the Paleobotanical Collection at Indiana University, Bloomington, Indiana.

GEOLOGY

Gray Butte and its surroundings seem to represent a large block of crust uplifted to the northwest and dipping to the southeast. Williams (1957) interpreted the feature as one slope

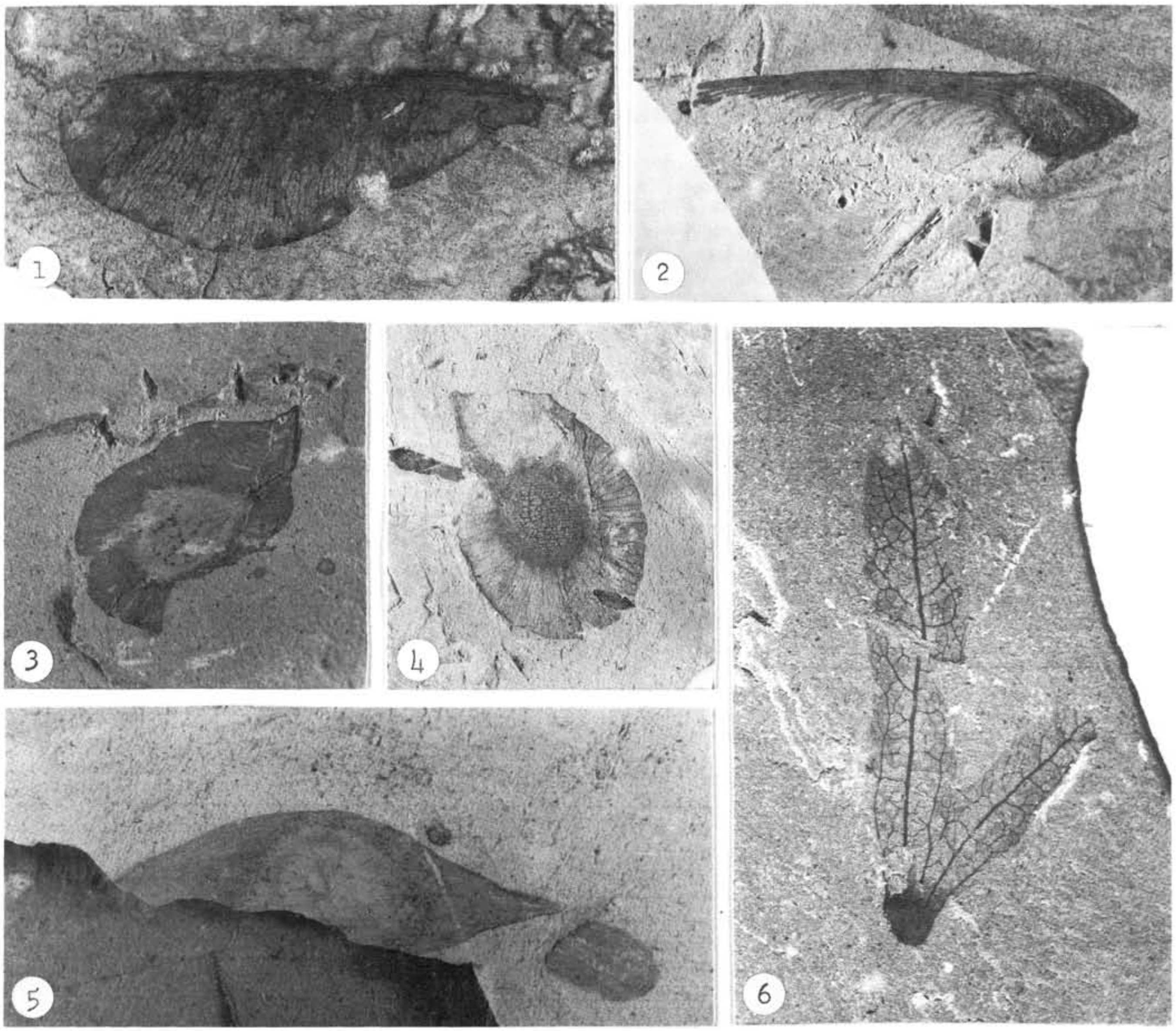

Figure 2. Sumner Spring flora: 1 and 2, winged fruits of Acer *(maple), X2; 3 and 4, winged fruits of* Dipteronia*, X3; 5, winged fruit of* Ailanthus *(tree-of-heaven), X4; 6, winged fruit of* Engelhardia *(walnut family), X4.*

of an anticline trending northeast-southwest and plunging to the southwest. The formations and their strata are exposed in progressively younger sequence from the northwest to the southeast (Robinson and Stensland, 1979), culminating in the Columbia River Basalt Group southeast of Lone Pine Flat and in the Miocene-Pliocene Deschutes Formation (Newcomb, 1970) and Pleistocene lake terraces (Brogan, personal communication, 1970) in the Prineville basin.

The occurrence of marble of possible Paleozoic age (Ashwill, 1979) and the discovery of a Permian fusulinid in a cobble from a dry creek bed at the base of Gray Butte (Thompson and Wheeler, 1942) suggest that the area is more complex tectonically than is suggested by the most recent regional geologic map (Robinson and Stensland, 1979).

The Sumner Spring localities occur in lacustrine shales mapped as Clarno Formation by Robinson and Stensland (1979). Although the Clarno Formation is Eocene throughout most of its extent in north-central Oregon, a whole-rock potassium-argon date of about 31 m.y. (Oligocene) was obtained from basalt attributed to the Clarno Formation on the north side of Gray Butte (unpublished data by P.T. Robinson and E.H. McKee, cited *in* Fiebelkorn and others, 1983, p. 23).

FLORAL COMPOSITION

Introduction

Although more than 250 specimens have been collected, only 11 species have been identified to the genus level. Five additional taxa can be distinguished but remain unidentified. Many specimens still require identification, but most of the floral assemblage appears to be represented in this paper. The fossil remains include leaves and reproductive structures. Most of the fossil fruits and seeds were winged species, which may represent a bias toward deposition of wind-carried debris in the lake environment.

Ten of the species found at Sumner Spring occur in the Nut Beds and/or in the West Branch Creek localities of the Clarno Formation. Nine of the species occur in the Bridge Creek flora or other classical Oligocene floras. Six species of the Sumner Spring

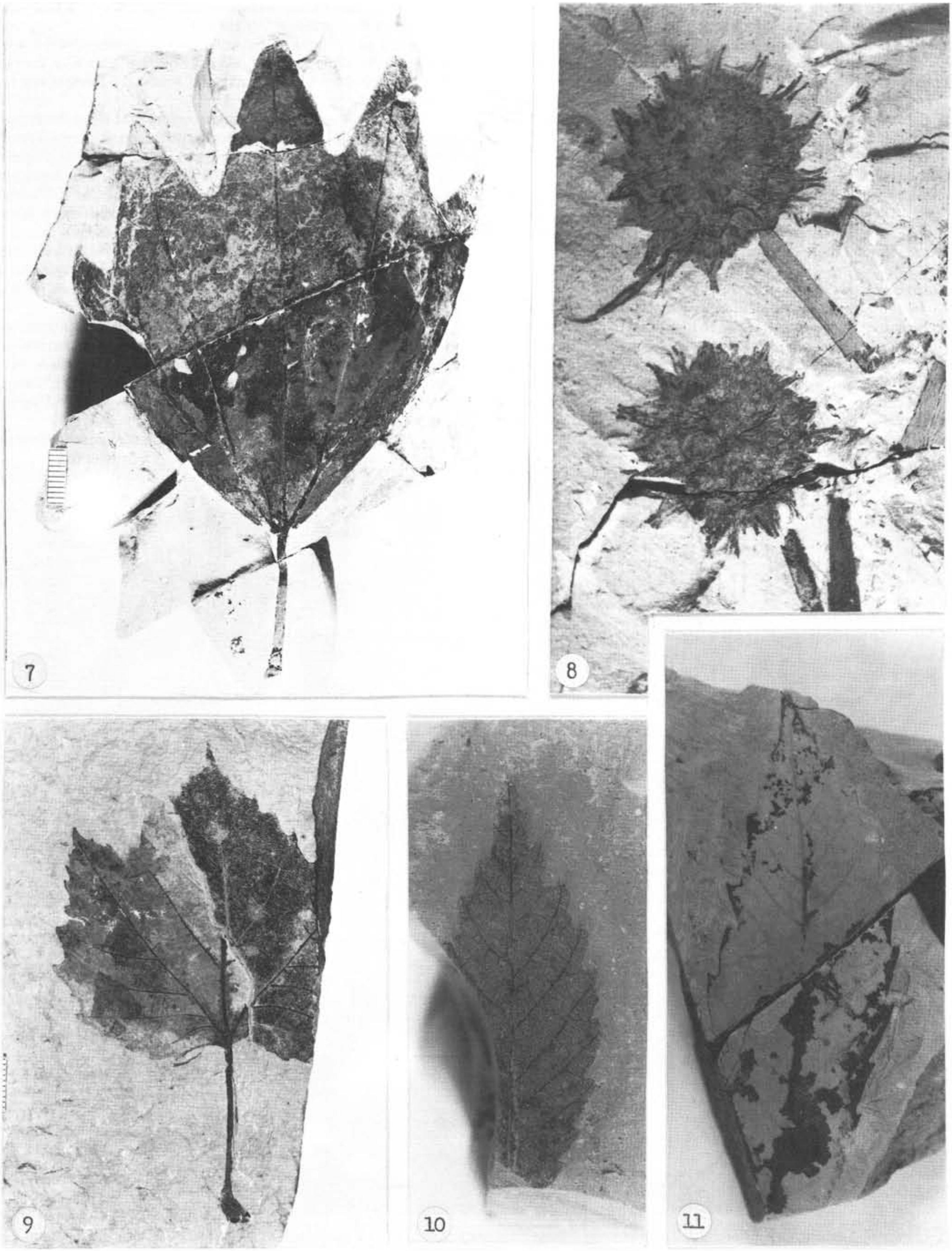

Figure 3. Sumner Spring flora: 7, Platanophyllum whitneyi *leaf, an extinct type of sycamore, X1; 8, fruiting bodies associated with the* Platanophyllum whitneyi *leaves, X3; 9,* Platanus *sp. similar to those of modern sycamore, X1; 10,* Zelkova *sp. (elm family), X3; 11,* Quercus simulata *(oak) X1.*

flora occur in both the Clarno and John Day Formations. A systematic list of floral composition is given in Table 1, and specimens are shown in Figures 2, 3, and 4.

Pteridophyta

A three-dimensional fragment and several compressed stems of *Equisetum* have been recovered by Ashwill from the Sumner Spring flora.

Gymnospermae

Site 75 has yielded seeds resembling *Picea* (Pinaceae) (Figure 4, no. 14) and a cone scale of the genus *Pinus* (Pinaceae) (Figure 4, no. 13). A fossil branch belonging to the family Taxodiaceae was also found there (Figure 4, no. 12).

Angiospermae

In addition to leaves, numerous winged fruits and flowers representing five species have been identified in the fossil flora. Samaras of at least one species of *Acer* (Aceraceae) are present (Figure 2, nos. 1 and 2). Although *Acer* is common in the John Day Formation, it has not been reported in the Clarno Formation. Fruits of the related genus *Dipteronia* (Aceraceae) are present in the flora (Figure 2, nos. 3 and 4). *Dipteronia* has not been previously recorded in the literature from either the John Day or Clarno Formations but has been found recently in sediments of the Clarno Formation at Dry Hollow.

The walnut family (Juglandaceae) is represented by tri-winged fruits of the genus *Engelhardia* (Figure 2, no. 6). It is well represented in both the Clarno and John Day Formations in Oregon.

Most abundant among specimens found at Gray Butte are foliage and associated fruiting heads of *Platanophyllum whitneyi* (Platanaceae), an extinct member of the sycamore family (Figure 3, nos. 7 and 8). Baldwin (1976, Figure 6.10) illustrates an example of a sycamore leaf from OMSI locality 78. The same kinds of leaves and fruits occur in the Eocene Chalk Bluffs flora of California (MacGinitie, 1941), but this is its only known occurrence in Oregon. One leaf fragment of *Platanophyllum angustiloba* possessing several teeth along the margin was collected from OMSI locality 75. Also found were several leaves of *Platanus* sp., or true sycamore (Figure 3, no. 9).

Fossil leaves that have been tentatively identified as *Quercus simulata* Knowlton (Fagaceae), an evergreen oak, occur in shales of the Sumner Spring flora (Figure 3, no. 11). *Q. simulata* occurs in the Miocene Blue Mountain localities of Oregon (Chaney, 1959) but has not been recorded previously in the Clarno Formation.

One winged fruit of the genus *Ailanthus* (Simaroubaceae)

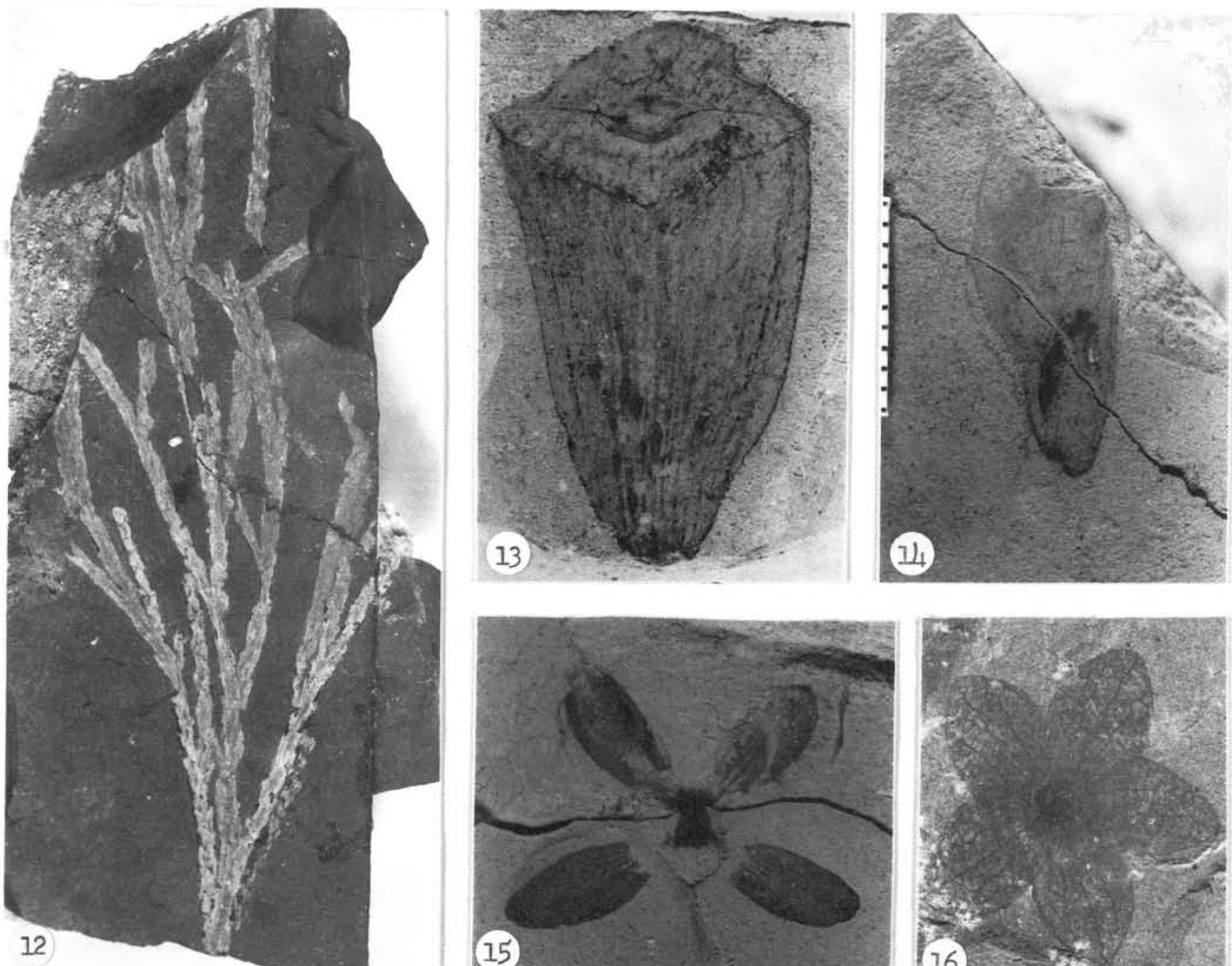

Figure 4. Sumner Spring flora: 12, Taxodiaceous foliage (sequoia family), X2; 13, cone scale of Pinus *(pine), X3; 14, winged seed of* Picea *(spruce), X3; 15, Four-winged* Tetrapteris-*like fruit, X3; 16,* Holmskioldia-*like flower, X2.*

Table 1. *Fossil plants of the Sumner Spring flora and their occurrence in floras of the Clarno and John Day Formations*

Gray Butte taxa	**Nut Beds: Eocene Clarno Formation**	**West Branch Creek: Eocene Clarno Formation**	**Bridge Creek: Oligocene John Day Formation**
Pteridophyta			
Equisetum sp.	X	X	X
Gymnospermae			
Picea sp.	——	——	——
Pinus sp.	——	X	X
Taxodiaceae	X	X	X
Angiospermae			
Acer sp.	——	——	X
Ailanthus sp.	——	X	——
Dipteronia sp.	——	——	——
Engelhardia sp.	X	X	X
Holmskioldia sp.	——	X	X
Platanophyllum angustiloba	X	X	——
Platanophyllum whitneyi	——	——	——
Platanus sp.	——	——	X
Quercus simulata	——	——	X
Tetrapteris sp.	X	X	——
Typha sp.	X	——	——
Zelkova sp.	——	X	X

(tree-of-heaven) has been recovered from OMSI locality 75 (Figure 2, no. 5). *Ailanthus* is found in the Eocene Clarno Formation but not in the younger sediments of the John Day Formation.

A small *Zelkova* (Ulmaceae) leaf has been identified from OMSI locality 75 (Figure 3, no. 10). It is found in both the Clarno and John Day Formations.

Abundant four-winged fruits (Figure 4, no. 15) that have not yet been identified are present in both exposures. Wings radiate from a central nutlet in cruciform orientation. The wings are up to 5 mm wide and 10 mm long and are obovate to spatulate with constricted and decurrent bases and rounded apices. Venation is parallel but flares slightly toward the apex of each wing. These fruits resemble those of *Tetrapteris simsoni* (Malpigiaceae) (Brown, 1940) but are about a third as large and differ somewhat in wing shape from *T. simsoni.* Numerous five-sepaled flowers have been recovered from the Sumner Spring flora (Figure 4, no. 16). These remain unidentified but are similar to those of *Holmskioldia.*

In addition to the dicots discussed above, several portions of monocot lamina resembling *Typha* (Typhaceae) have been found in the fossil flora. Palms have not been recovered.

CONCLUSION

The Sumner Spring flora shows similarities in composition to classical localities of the Clarno and John Day Formations, as represented by the Nut Beds and West Branch Creek and Bridge Creek floras (Table 1). The lack of plants of true tropical nature, such as palms, and the relatively low diversity of the flora seem to indicate a temperate climate. The presence of *Acer* and *Platanus*, which elsewhere are lacking in the Clarno Formation but present in the John Day Formation, suggests that the Sumner Spring flora is younger than the Nut Beds and other typical Clarno localities. Although the Sumner Spring localities are mapped as Clarno Formation (Robinson and Stensland, 1979), these floral considerations suggest that the Sumner Spring localities are younger than typical Clarno flora and perhaps closer in age to floras known from the lower part of the John Day Formation. Possibly the Sumner Spring flora is Oligocene in age.

ACKNOWLEDGMENTS

Many thanks are due to Melvin S. Ashwill, Madras, Oregon, for assistance with the geology of the area and in collection and donation of fossil specimens; Steven R. Manchester, Department of Geology, Indiana University, Bloomington, Indiana, for help and advice; OMSI summer paleoecology teams of 1980 and 1981 for collections; and Mr. and Mrs. Hugh J. McFadden, Kennewick, Washington, for monetary support.

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*(Continued on page 58, **Fossil flora**)*

ABSTRACTS

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

THE UNITY RESERVOIR RHYODACITE TUFF-BRECCIA AND ASSOCIATED VOLCANIC ROCKS, BAKER COUNTY, OREGON, by John W. Reef (M.S., Washington State University, 1983)

Previous work concerning the volcanic breccia at Unity Reservoir has been restricted to brief and varied descriptions of the unit. It was believed that the breccia was similar to and continuous with the widespread volcaniclastics to the north (Clarno conglomerate). Prior to this study an origin for the breccia had not been presented.

This investigation has shown that the Unity Reservoir tuff-breccia forms a distinct lithologic unit within the Unity, Unity Reservoir, and Hereford quadrangles. It is locally overlain by a rhyodacite flow, and a small exposure of an upper breccia locally overlies the flow. Both breccias consist of a homogeneous assemblage of volcaniclastic debris of rhyodacitic composition in which angular to subangular blocks make up approximately 35 percent of the unit. The blocks in the main breccia have phenocrysts of plagioclase, basaltic hornblende, orthopyroxene, and clinopyroxene in a hyalopilitic groundmass of plagioclase, magnetite, and glass. The upper breccia has phenocrysts of plagioclase, quartz, orthopyroxene, clinopyroxene, and biotite. The matrix of both breccias consists of angular to subrounded lapilli and ash-sized fragments similar in composition to the blocks. Poor fossil evidence suggests an Eocene age for the breccia.

The breccia is greater than 300 m thick. Throughout most of the unit, the blocks and matrix are randomly distributed, but near the top of the unit, variations in the proportions of blocks to matrix impart a crude stratification to the deposit. The homogeneity; poorly developed stratification; angularity of the blocks and matrix; and the absence of pumice, glass shards, brecciated dikes or vent structures, lateral grading, gravity sorting, or features indicating emplacement at high temperatures indicates that the breccia is of laharic origin.

The Clarno conglomerate, found north of the study area, is separated from the breccia by a younger rhyolite flow that prevents direct correlation. The Clarno conglomerate, however, consists of blocks of dacite, basalt, andesite, and rhyolite and is clearly different from the homogeneous rhyodacites of the Unity Reservoir tuff breccia.

Dooley Rhyolite is reported to overlie the rhyodacites of the study area, but it has not been previously described. It has been found during this investigation to consist of three distinct ignimbrite flow units. Each unit is welded and believed to represent an incomplete section of a layer-2 deposit. Analyses show that each ignimbrite unit can be distinguished from the others on the basis of petrographic and chemical characteristics.

THE QUEEN OF BRONZE COPPER DEPOSIT, SOUTHWESTERN OREGON: AN EXAMPLE OF SUB-SEA MASSIVE SULFIDE MINERALIZATION, by Mark Randall Sorensen (M.S., University of Oregon, 1983)

The Queen of Bronze is a copper-rich massive sulfide deposit located in the western Paleozoic and Triassic belt of the Klamath Mountains. Field and petrochemical evidence is consistent with formation of the igneous host rocks in an oceanic setting, perhaps a back-arc basin. There are two types of hydrothermal alteration: (1) ore-related envelope alteration; and (2) hydrothermal metamorphism, which occurred after envelope alteration. The strong enrichment of altered rocks in FeO and depletion in SiO_2, as well as locally abundant cobaltite in the ores, suggest that mineralization proceeded at high temperatures (near 400°) and low pressures. Ore from the mine differs from typical massive sulfide ores in having abundant, early euhedral quartz. The bulk of the geologic evidence implies that mineralization occurred due to cooling of hydrothermal solutions in large open spaces, probably fissures, in the sub-sea floor.

THE "TOPS" OF PORPHYRY COPPER DEPOSITS — MINERALIZATION AND PLUTONISM IN THE WESTERN CASCADES, OREGON, by Sara G. Power (Ph.D, Oregon State University, 1984)

The mining districts of the Western Cascades and their associated epizonal plutons and locally extensive zones of hydrothermally altered rocks are roughly parallel to the northerly trend of the Quaternary High Cascades. The volcanic rocks range in age from Oligocene (Washougal and Bohemia districts) to mid-Miocene (North Santiam, Detroit Dam, Quartzville, and Blue River districts). These volcanic rocks are intruded by numerous plutons of intermediate composition. Both plutonic and volcanic rocks have calc-alkaline affinities, and the chemical composition of the intrusions resembles that of plutons from island-arc terrains. Ages of plutons in the Washougal (20 m.y.), North Santiam (13 m.y.), Blue River (13 m.y.), and Bohemia (22 m.y.) districts are consistent with the geology of these areas. Ages of hydrothermal alteration in the Washougal (19 m.y.) and North Santiam (11 m.y.) districts suggest a direct genetic relationship between mineralization and spatially associated plutons of granodiorite and quartz diorite porphyries and porphyritic granodiorite, respectively.

Hydrothermal alteration of plutonic and volcanic host rocks in and adjacent to the mining districts of the Western Cascades is dominated by the propylitic assemblage. Argillic and phyllic assemblages are more local and are controlled by structure, especially near the base and precious-metal-bearing vein deposits. Potassic alteration is associated with porphyry-type mineralization in the Washougal and North Santiam districts and with a one-sample Cu-Mo anomaly in the Bohemia district. Vein-type mineralization is largely defined by subequal amounts of Cu and Zn together with lesser quantities of Pb, whereas that of the porphyry-type is dominated by Cu.

Sulfur isotope compositions of the sulfide minerals range from 5.1 to 5.0 permil and average about 1.7 permil. This relatively narrow range of $\delta^{34}S$ values near 0 permil is consistent with a magmatic derivation for the sulfur. Isotopic temperature estimates indicate sulfide deposition in veins at 200° to 500° C and up to 675° C in porphyry-type environments. Homogenization temperatures and salinities of fluid inclusions in vein quartz range from 167° to 319° C and from 0 to 18 wt percent NaCl, respectively. In contrast, those of halite-bearing inclusions associated with breccia pipes and potassically altered plutons exceed 386° C and 30 wt percent NaCl. The depth of cover at the time of mineralization is estimated to range from 740 m in the North Santiam district to 1,800 m in the Washougal district.

Geologic and geochemical evidence collectively suggest that porphyry-type copper and molybdenum mineralization may underlie many if not all mining districts of the Western Cascades. □

GRC announces meetings

Annual Meeting: The Geothermal Resources Council (GRC) will hold its 1986 Annual Meeting September 29 to October 1 at the Americana Canyon Hotel in Palm Springs, California. The meeting is intended to provide a forum for exchange of new and significant information on all aspects of the exploration, development, and use of geothermal resources.

The meeting's program will offer presentations at oral and poster sessions, field trips, and special events. Announcement of the program will be made at a later date. The deadline for papers for the meeting and subsequent publication in the GRC *Transactions* is April 25, 1986.

In conjunction with the meeting, the GRC will hold its 10th annual photography contest to recognize artistic ability in photographing geothermal development and to augment the GRC photo library. Winning entries will be displayed at the meeting. Entries for the contest must be received in the GRC office by August 15, 1986.

Direct-use workshop at OIT: A topical workshop on the direct (nonelectrical) uses of geothermal energy has been announced by its sponsors, the Geothermal Resources Council (GRC), the Geo-Heat Center of the Oregon Institute of Technology (OIT), and the Pacific Northwest Section of the GRC. The workshop will be held May 20-22, 1986, in the Mount Shasta Complex of the geothermally heated OIT campus at Klamath Falls.

The workshop will include approximately 40 short presentations, a panel, and a round-table discussion, all concerning direct-use development, applications, and equipment. A display/exhibit area for interested manufacturers, suppliers, institutions, or agencies will be set up near the meeting room. There will also be a field trip to tour various geothermal sites to inspect direct-use equipment and applications.

The comprehensive fee for the course is $150; stuents may attend for a fee of $5 per day. Optional college credit for the workshop is offered for an addition al fee of $58.

For more information and registration contact the GRC, P.O. Box 1350, 111 G Street, Suite 29, Davis, CA 95617-1350, phone (916) 758-2360. □

USGS employees receive service awards at Western Region convocation

Department of Interior service awards for outstanding achievement in their respective fields were presented to U.S. Geological Survey (USGS) employees on the staff of the Survey's Western Region headquarters at a recent convocation in Menlo Park, California. Two of the awards will be of particular interest to *Oregon Geology* readers.

William Porter Irwin, USGS geologist from Menlo Park, California, received a meritorious service award for his achievements as a geologic mapper and as an innovator of new scientific concepts. His geological studies, initially on the northern California Coast Ranges and later in the Klamath Mountains, are credited with being instrumental in developing concepts leading to important interpretations of oceanic plate movement and tectonic analysis. In the words of the citation, "he was the first to understand that the Klamath Mountains are made up of a series of thrust sheets, each composed of different materials that record highly varying geologic histories. The separate entities were designated 'terranes' and were recognized to be the fundamental building blocks out of which the continental crust of the Klamath Mountains was assembled."

A 40-year length of service award was given to geologist George Walker of Los Altos, California, identified to his geologic colleagues as "Mr. Oregon Geologist." Walker, who holds A.B. and M.S. degrees from Stanford University, was commended for his mapping and studies of the geology of Oregon "on all scales and from many angles."

USGS Associate Director Doyle Frederick of the National Center, Reston, Virginia, presented the awards and gave the principal address. George Gryc, Western Region director's representative, presided at the ceremonies.

— *USGS press release*

First reports commissioned by Gorda Ridge Task Force released

Four open-file reports reviewing existing biological data on the Gorda Ridge and vicinity off the coast of southern Oregon and northern California have been prepared by the Oregon State University (OSU) College of Oceanography and released by the Oregon Department of Geology and Mineral Industries (DOGAMI). The reports all have the general title, *A Summary of the State of Scientific Information Relating to the Biology and Ecology of the Gorda Ridge Study Area, Northeast Pacific Ocean.* Open-File Report 0-86-6 reviews literature on benthos, 0-86-7 on nekton, 0-86-8 on plankton, and 0-86-9 on seabirds.

The reports are the first results of a series of studies commissioned by the joint Federal-State Gorda Ridge Technical Task Force during March 1985. The Task Force was formed in February 1984 and is charged with conducting a technical analysis of the economic and environmental implications of leasing the Gorda Ridge for the mining of polymetallic sulfide minerals. Funding was provided by the U.S. Minerals Management Service. The reports are intended for use in identifying appropriate research to support decision making for possible development on the outer continental shelf.

Open-File Report 0-86-6, *Benthos,* was written by Michael A. Boudrias and Gary L. Taghon. The 58-page report summarizes the available literature on all bottom-dwelling organisms in the study area and includes a section on the species found surrounding hydrothermal vents elsewhere in the Pacific.

Open-File Report 0-86-7, *Nekton,* was written by James T. Harvey and David L. Stein. It is 131 pages long and summarizes available knowledge on shrimps, cephalopods, fishes, and marine mammals in the study area. Biological data, including abundance, distribution, reproduction, growth, migration, food habits, and commercial exploitation, are summarized for each species for which there is information.

Open-File Report 0-86-8, *Plankton,* was written by Steven G. Ellis and Jonathan H. Garber. This 47-page document summarizes phytoplankton and zooplankton abundance and distribution and discusses the feeding ecology of major zooplanktonic groups in the study area.

Open-File Report 0-86-9, *Seabirds,* is 27 pages long and was written by Lynn D. Krasnow. It discusses seabird densities and movements at sea, colony sites, population estimates, feeding habits, growth, and behavior and contains a list of species of seabirds known or thought to exist in the Gorda Ridge study area.

The reports are now available for sale at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201-5538. Purchase prices of the reports are as follows: 0-86-6 (*Benthos*), $5; 0-86-7 (*Nekton*), $7; 0-86-8 (*Plankton*), $5; and 0-86-9 (*Seabirds*), $4. Orders under $50 require prepayment. □

DOGAMI hires industrial minerals geologist

Ronald P. Geitgey has joined the staff of the Oregon Department of Geology and Mineral Industries (DOGAMI) as industrial minerals geologist. He is a graduate of the College of Wooster in Wooster, Ohio, and the University of Virginia at Charlottesville and has done additional graduate work at the University of New Mexico at Albuquerque. Geitgey was employed as geologist by Leonard Resources, Albuquerque, New Mexico, and as senior geologist for industrial minerals exploration by Duval Corporation, Tucson, Arizona.

Ronald P. Geitgey

During his career, Geitgey has directed exploration and drilling operations in borates, coal, oil and gas, potash, sulfur, uranium, and zeolites, with additional experience in exploration and evaluation of cement rock, clays, diatomite, geothermal resources, magnesite, perlite, phosphate, sodium sulfate, and trona. He has worked with numerous analytical techniques and has had experience in establishing and coordinating industrial minerals analytical programs.

His responsibilities with DOGAMI will be to conduct geologic investigations of nonmetallic mineral deposits of probable economic potential and to serve as the Department's information source on nonmetallic mineral resources and markets. He is currently involved in an evaluation of bentonite in Oregon, a part of the Department's new program to define markets and to evaluate the industrial mineral resources of the state. □

New USGS topo maps of Mount Hood area have many features

Two multicolored topographic maps of the Mount Hood, Oregon, volcanic area, printed back-to-back on the same sheet and containing a wide variety of topographic, hydrologic, and geographic information, have been recently published by the U.S. Geological Survey (USGS).

One side of the Mount Hood-area sheet contains a map printed at a scale of 1:24,000 (1 in. on the map represents about 2,000 ft on the ground) and depicts about 235 sq mi of land surface in Oregon. The other side has a map printed at a scale of 1:100,000 (1 in. represents about 1.6 mi) and shows a much larger area of about 4,550 sq mi of Oregon and Washington.

The Mount Hood maps, which were prepared cooperatively by the USGS National Mapping Division and the USGS Water Resources Division, are printed on both sides of a 30- by 60-in. sheet. The 1:24,000-scale map can be used by land-use planners, administrators, government and industry, and also by hikers, campers, and other outdoor enthusiasts as a detailed guide to areas on and immediately around Mount Hood, including the Mount Hood Wilderness. Trails and campgrounds are depicted, along with streams, lakes, snowfields, glaciers, roads, and cultural features. Contours and elevations are shown in feet.

For the first time on a USGS map, the 1:24,000-scale map portrays and tabulates the volumes of ice locked in the glaciers and permanent snowfields on Mount Hood. The USGS Water Resources Division tabulated the ice volumes by individual basins in order to analyze potential mudflow and flood hazards during possible volcanic eruptions of Mount Hood.

USGS hydrolologists estimated that about 12.2 billion cu ft of ice is on Mount Hood in glaciers and permanent snowfields. That is equal to more than half the water normally in Lake Bonneville on the Columbia River. The total includes 8.6 billion cu ft for the Hood River basin, 1.7 billion cu ft for the Sandy River, 1.4 billion cu ft for the Zigzag River, and 500 million cu ft for the White River.

The three major rivers in the Mount Hood region — the Columbia, Deschutes, and Sandy, generally mark the boundaries of the 1:100,000-scale map. The area's two major public-supply surface-water reserves — the Bull Run for Portland and the Dalles for the city of The Dalles — are outlined.

The 1:100,000-scale map includes areas likely to be affected by mudflows, flooding, and other volcanic hazards. It also provides information on federal lands, including the Mount Hood National Forest, and indicates areas of responsibility for land management by federal and state agencies. In addition, it shows contours and elevations of peaks and other places in meters.

As an aid to forest visitors, both sides of the map use the U.S. Forest Service road-numbering system. Roads are designated as primary or secondary roads or trails.

The "Mount Hood and Vicinity" map sheet is available in a folded edition either by mail or over the counter for $6 from the Portland office of the Oregon Department of Geology and Mineral Industries. It is also available from usual USGS and commercial outlets. □

***(Fossil flora,** continued from page 55)*

U.S. Geological Survey Miscellaneous Geologic Investigations Map I-587.

Robinson, P.T., and Stensland, D.H., 1979, Geologic map of the Smith Rock area, Jefferson, Deschutes, and Crook Counties, Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I-1142.

Thompson, M.L., and Wheeler, H.D., 1942, Permian fusulinids from British Columbia, Washington, Oregon, and Idaho: Journal of Paleontology, v. 16, p. 700-711.

Tidwell, W.D., 1975, Common fossil plants of western North America: Provo, Utah, Brigham Young University Press, 197 p.

Vance, A.D., 1936, With Dr. Chaney in eastern Oregon: Geological Society of the Oregon Country, Geological Newsletter, v. 2, no. 16, p. 2-4.

Williams, H., 1957, A geologic map of the Bend quadrangle and a reconnaissance geologic map of the central portion of the High Cascade Mountains: Oregon Department of Geology and Mineral Industries Quadrangle Map. □

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Information for contributors

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

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

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

COVER PHOTO

Northward view across Lake Simtustus on the Deschutes River. Article beginning on next page discusses the Simtustus Formation, shown on this photo as unit *Ts* interstratified with and overlying Columbia River basalt flows (*Tcr*). Dashed line denotes approximate position of unconformity between the Simtustus (*Ts*) and Deschutes (*Td*) Formations. Ledge-forming basalt above the unconformity is the Pelton basalt member. Mutton Mountains are on the skyline.

Notice of change

During the next one month or two the mailing of *Oregon Geology* will undergo some significant — and we hope beneficial — changes. The mailing itself will be taken over by a mailing service outside the Department, and the maintenance of the mailing list will be handled with the help of a computer.

Please bear with us, if some problems occur during the transition. Let us know soon if you do not receive your magazine or if your address should not be quite correct. That address, by the way, will include a code number whose last four digits will tell you the expiration month and year of your subscription. Please take note of it as a timely reminder to renew!

— *The editors*

DOGAMI releases open-file reports

Geothermal gradient data for 1982-1984: The Oregon Department of Geology and Mineral Industries (DOGAMI) has released geothermal gradient data collected from 1982 through 1984 and placed them on open file as Open-File Report O-86-2.

The 107-page report contains all temperature-gradient measurements taken by the staff of DOGAMI and the Oregon Department of Water Resources in 42 drill holes throughout the state. For each of the drill holes, which are arranged by township from north to south, the computer-produced report contains data tables and temperature-depth plots as graphic summaries.

The report was compiled by D.D. Blackwell, Southern Methodist University, G.L. Black and G.R. Priest, DOGAMI, and funded by a grant from the U.S. Department of Energy (price, $5).

Inventory of data on coastal black sands: A comprehensive inventory of existing data on coastal heavy-mineral-bearing "black sands," a potential source of such strategic metals as chromium and titanium, has also been released by DOGAMI. The new release, DOGAMI Open-File Report O-86-10, is entitled *Inventory of Heavy Minerals and Metals — Southern Washington, Oregon, and Northern California Continental Shelf and Coastal Region* and contains data summaries of some 93 studies.

The new publication is part of the efforts by State and Federal agencies investigating the newly expanded areas under United States jurisdiction proclaimed in 1983 as Exclusive Economic Zone (EEZ). The report was produced by the Oregon State University College of Oceanography with funding from the U.S. Minerals Management Service. The authors are marine geologists LaVerne D. Kulm, Curt D. Peterson, and Margaret C. Stribling.

The 111-page report is divided into three major sections. The text outlines a long-range plan for exploration and research of heavy-mineral-bearing sands. A graphic section includes a series of 38 maps representing all the types of data collected between 41° and 47° N. latitude. Finally, the report contains a summary of the data generated by each of the 93 studies. Each summary lists the source of the information, locational and topical information, morphological information, methods of data collection, and the data acquired in the study (price, $8).

Both reports are available for sale from the Portland office of the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. Orders under $50 require prepayment.□

Simtustus Formation: Paleogeographic and stratigraphic significance of a newly defined Miocene unit in the Deschutes basin, central Oregon

by Gary A. Smith, Research Fellow, Northwest College and University Association for Science, Tri-Cities University Center, Richland, WA 99352

ABSTRACT

Volcanogenic sandstones, mudstones, and tuffs of middle Miocene age in the northern Deschutes basin are conformable upon and intercalated with lava flows correlated to the Grande Ronde Basalt of the Columbia River Basalt Group. Although previously mapped as Deschutes Formation (or equivalent), the middle Miocene sediments are lithologically distinct from typical Deschutes Formation rocks, and the two units are separated by an angular and erosional unconformity representing a hiatus of 5 to 7 million years (m.y.). The name Deschutes Formation is retained for the younger sequence, and the name Simtustus Formation is herein proposed for the older rocks. Fluvial channel and flood-plain aggradation during Simtustus time was probably induced by drainage disruption and base-level rise associated with emplacement of the voluminous Columbia River flood basalts. Western Cascade volcanoes were the provenance for most Simtustus Formation sandstones, but these sandstones are dominated by pyroclastic debris which is subordinate to other lithologies in the contemporary Western Cascades volcanic sequences. This discrepancy reflects preferential erosion of unconsolidated pyroclastic debris from proximal volcanic centers and its subsequent enrichment, relative to epiclastic material eroded from lava flows, among sediment deposited in distal sedimentary basins.

INTRODUCTION

The Tertiary stratigraphy of central and eastern Oregon is characterized by sequences of volcanic and nonmarine, largely volcanogenic, sedimentary rocks (Walker, 1977). Although many of the volcanic rocks have been the subject of petrologic and stratigraphic study, little effort has been made to evaluate the stratigraphy and sedimentology of the sedimentary units or their paleogeographic and tectonic significance. Many of the sedimentary units host fossil floras and faunas that have been the subject of paleontological scrutiny for over a century, but rarely were these studies coupled with stratigraphic investigations. As a result, the contact relationships of paleontologically dated units with adjacent rocks are generally unknown, the lithologies are often undescribed, and stratigraphic nomenclature is either lacking altogether or ambiguously defined from reconnaissance mapping.

This paper describes a newly recognized Miocene unit, herein named the Simtustus Formation, in the Deschutes basin of central Oregon, and discusses its depositional environment, relations to previously defined units, and significance to regional stratigraphy. Of particular importance is the interstratification of the Simtustus Formation with basalts correlative to the Columbia River Basalt Group. A recognized stratigraphy exists for sedimentary rocks interbedded with the Miocene flood basalts in most of central and eastern Washington (Swanson and others, 1979), but a comparable understanding of interbed stratigraphy is lacking for Oregon.

The Deschutes basin is that area of central Oregon south of the Mutton Mountains, north of the High Lava Plains, east of the High Cascade Range, and west of the Ochoco Mountain foothills

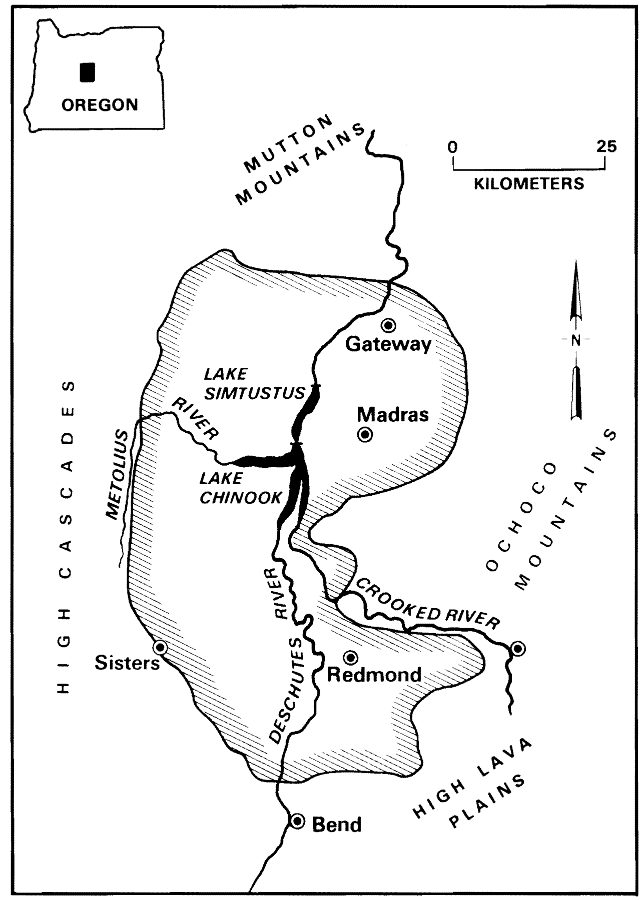

Figure 1. Location map of central Oregon showing limits of the Deschutes basin (shaded area).

(Figure 1). This region, currently integrated into the Columbia River drainage system via the north-flowing Deschutes River, has been the site of episodic emplacement of volcanic and volcanogenic sedimentary rocks since at least middle Eocene time. Surface exposure is dominated by rocks of Neogene age derived both from the Cascade Range and volcanic sources within and east of the basin.

Exposures of the middle to upper Eocene Clarno Formation and Oligocene to lower Miocene John Day Formation are largely restricted to structurally high areas north and east of the Deschutes basin. Large rhyolite domes and smaller knobs of dacite assigned to the John Day Formation (Smith, 1986) also occur as inliers within the basin, surrounded and partially buried by younger rocks.

The John Day Formation is unconformably overlain by middle Miocene basalt flows of Prineville chemical type (Uppuluri, 1974), which are stratigraphically equivalent to the Grande Ronde Basalt of the Columbia River Basalt Group (Smith, 1986). The Grande Ronde Basalt is the oldest of three formations in the Yakima Basalt Subgroup that are widespread in central and eastern Washington and northern Oregon and that were erupted from fissure vents in southeastern Washington and northeastern Oregon. The Prineville chemical-type flows in the Deschutes basin were probably erupted from now-buried vents located south of Powell Buttes and then flowed northward through the basin and were intercalated with Grande Ronde Basalt flows north of the Mutton Mountains. Correlation of Prineville chemical-type flows in the Deschutes basin with flows of similar composition within the Grande Ronde Basalt farther north (Swanson and others, 1979) warrants inclusion of the Deschutes basin basalts within the Grande Ronde Basalt (Smith, 1986).

Within the basin, middle Miocene basalts are overlain by and intercalated with volcanic and volcaniclastic rocks of largely Cascade provenance that comprise the Simtustus and Deschutes Formations. Pleistocene basalt flows and pyroclastic deposits locally overlie the Neogene section and partly fill 50- to 250-m-deep canyons incised during late Pliocene and early Pleistocene time by the Deschutes River and its tributaries. The base of the exposed section is progressively older to the north as a result of northward increase in the depth of incision and southerly dips on the south flank of the Mutton Mountains.

PREVIOUS WORK

Volcanic and sedimentary rocks of Miocene to early Pliocene age overlying the Columbia River Basalt Group in the Deschutes basin have been referred to by three names. These rocks have been named (1) Deschutes sands (Russell, 1905) or Deschutes Formation (Stearns, 1930; Moore, 1937; Stensland, 1970; Taylor, 1973, 1980; Peterson and others, 1976; Jay, 1982; Hayman, 1983; Farooqui and others, 1981a,b; Smith and Priest, 1983; Smith, 1986); (2) Madras Formation (Hodge, 1928,1940; Williams, 1957; Hewitt, 1970; Robinson and Price, 1963; Robinson and Stensland, 1979; Robinson and others, 1984); and (3) Dalles Formation (Hodge, 1942; Waters, 1968a; Robinson, 1975; Robison and Laenen, 1976). Farooqui and others (1981a,b) proposed retaining usage of Deschutes Formation because the name Deschutes has historic priority and placed the formation, along with other units in north-central Oregon that had been previously mapped as Dalles Formation, into their Dalles Group.

A type section was never defined by previous workers, but most have referred to exposures in the canyons of the Deschutes and Crooked Rivers upstream from Round Butte Dam as typical of the unit. In this region, the Deschutes Formation consists of dark-gray to black, pebbly, coarse-grained sandstones, cobble to boulder conglomerates, and minor tuffaceous mudstones and diatomites, interbedded with pumice lapillistones and more than a hundred ignimbrites and lava flows. Exposures illustrating this lithologic assemblage near Round Butte Dam have been suggested as a type section (Smith, 1986).

Studies of fossil leaves (Chaney, 1938; Ashwill, 1983) and fish bones (Cavender and Miller, 1972) indicate a late Miocene to early Pliocene age for the Deschutes Formation. Isotopic dates by $^{40}Ar/^{39}Ar$ methods indicate a range in age from about 7.6 million years (m.y.) (Smith and Snee, 1984) for the Pelton basalt member, the lowest basalt flow in the Deschutes Formation, to about 4.0 m.y. (L.W. Snee, personal communication, 1985) for basalts at the top of the formation. However, most of the Deschutes Formation was deposited prior to 5.6 million years before the present (m.y. B.P.)(Smith, 1986). Vertebrate fossils indicative of a Hemingfordian-Barstovian age (12.0 to 21.0 m.y.; all land mammal ages from Berggren and others, 1985) were described by Downs (1956) from localities near Gateway, which are stratigraphically between rocks of the Columbia River Basalt Group and rocks hosting Hemphillian-age (5.0 to 9.0 m.y.) fish fossils (Cavender and Miller, 1972) below the Pelton basalt member. The rocks hosting the Hemingfordian-Barstovian-age fossils were subsequently mapped as Dalles Formation (Waters, 1968a; Robinson, 1975) or lower Deschutes Formation (Hayman, 1983).

Jay (1982) and Hayman (1983) were the first workers to make a detailed evaluation of the stratigraphy of the Columbia River Basalt Group and overlying rocks in the Round Butte Dam to Gateway area. They designated all rocks overlying the Columbia River Basalt Group as Deschutes Formation, including those hosting Downs' (1956) fossils, thus extending the age of the base of the Deschutes Formation to middle Miocene. These two workers also recognized that the Columbia River Basalt Group is represented by two flows separated by a sedimentary interbed. Jay (1982) assigned the interbed to the Deschutes Formation, but Hayman (1983) mapped the interbed as a separate, unnamed unit.

Smith and Hayman (1983) gave a preliminary report of evidence for an unconformity separating Hemphillian fossil localities beneath the Pelton basalt member and Downs' (1956) Hemingfordian-Barstovian fossil localities. They proposed retaining Deschutes Formation for the upper unit and informally used Lake Simtustus formation for rocks below the unconformity and interbedded with the Columbia River Basalt Group. The name was shortened to Simtustus formation by Smith and Priest (1983) and Smith and Snee (1984) and has been reserved by the U.S. Geological Survey Geologic Names Committee (V. Langenheim, personal communication, 1984).

DEFINITION OF SIMTUSTUS FORMATION

Volcaniclastic rocks conformable upon, and interbedded with, the Columbia River Basalt Group in the Deschutes basin and lithologically distinct from other rocks in the basin are herein named the Simtustus Formation. Probable extension of the unit outside of this area is left for future workers. The name is derived from Lake Simtustus, the reservoir impounded behind Pelton Dam on the Deschutes River west of Madras (cover photo). The type section is defined and described from a composite of three exposures on the eastern canyon wall near the reservoir, and two reference sections are designated near Gateway (Figure 2; Smith, 1986). These sections illustrate most of the lithologic diversity of the formation but do not include an areally restricted rhyodacitic ignimbrite (Hayman, 1983; Smith and Hayman, in preparation) exposed on a hill 1.5 km southeast of Gateway. The general distribution of the Simtustus Formation is shown in Figure 3. However, the extent of the formation in the steep canyon walls is exaggerated for representation at this scale, and the reader is directed to other maps (Smith, 1986; Smith, in preparation,a,b; Smith and Hayman, in preparation) for more accurate portrayal.

As thus defined, the Simtustus Formation is 1 to 65 m thick and composed, in decreasing order of abundance, of tan, massive and laminated tuffaceous mudstone to fine-grained sandstone; light-gray to tan, cross-bedded medium- to very coarse-grained tuffaceous sandstone; small-pebble volcanic conglomerate; tuff; debris-flow breccia; and rhyodacitic ignimbrite. The name Deschutes Formation is retained for the coarse-grained volcanogenic sediments and interbedded lava flows and ignimbrites of variable composition that characterize the exposures first described by Russell (1905) and Stearns (1930) and that unconformably overlie the Simtustus Formation. These lithologies, which are distinct from the Simtustus Formation, have been considered in further detail by Stensland (1970), Hewitt (1970), Hales (1975), Jay (1982), Hayman (1983), Conrey (1985), Yogodzinski (1986), and Smith (1986). This definition represents a revision in the usage of Farooqui and others (1981a),

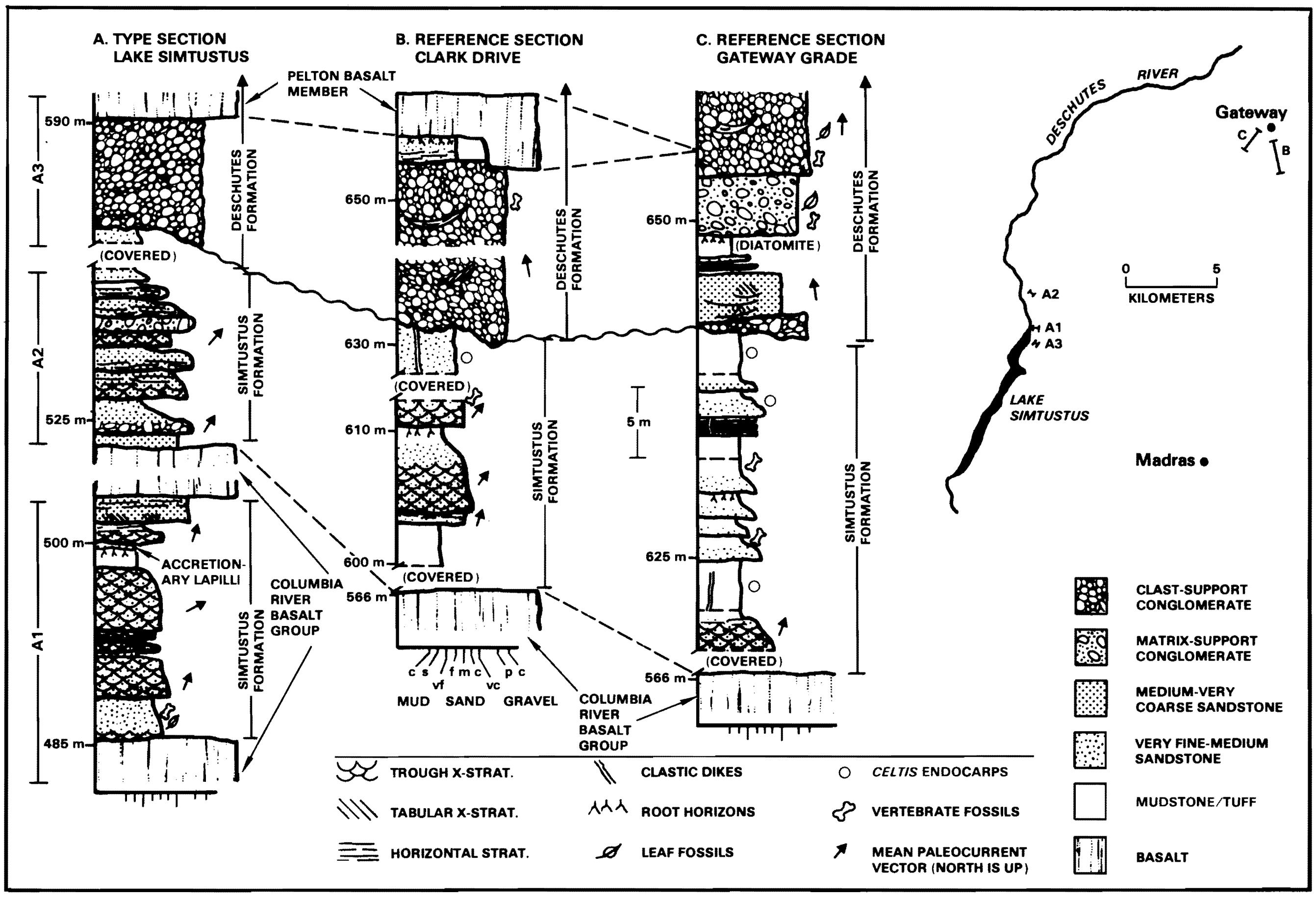

Figure 2. Graphic sections of the Simtustus Formation. Locations of all three sections shown on map in upper right corner of figure. Section A is a composite section of A1, A2, and A3.

which placed all Neogene rocks overlying the Columbia River Basalt Group in the Deschutes Formation including those now assigned to the Simtustus Formation.

Because of lithologic similarity between that part of the Simtustus Formation interbedded with the basalt and the part overlying the basalt, a single stratigraphic name is proposed. This designation follows the precedent of Swanson and others (1979), farther north on the Columbia Plateau, to restrict the Columbia River Basalt Group only to basalt and to assign sedimentary interbeds to the immediately overlying sedimentary formation of similar lithology. This approach is preferable to schemes that define formational boundaries in lithologically indistinct sedimentary units on the basis of position in the basalt sequence, because at the plateau margin, definitive basalt flows may not occur as markers (Schmincke, 1964; Swanson and others, 1979). To avoid ambiguous correlations of sedimentary units between sections with dissimilar basalt stratigraphy, member status in the Simtustus Formation is not designated for the prominent interbed in the basalts in the Deschutes basin, which hereafter is referred to informally as the lower Simtustus Formation for convenience in this paper.

Field relationships indicate that the Simtustus Formation is conformable with the Columbia River Basalt Group. In the Deschutes basin, no Simtustus Formation occurs below the Columbia River basalt that lies on the John Day Formation with up to 200 m of erosional relief and up to 10° of angular discordance (Smith, 1986). Lower Simtustus Formation sedimentation was probably initiated soon after the emplacement of the first basalt flow, because no paleosol occurs on the basalt. The second flow was emplaced during Simtustus deposition, because there is no evidence of disconformity. Locally, the second flow is invasive into lower Simtustus siltstone. The invasive relationship is recognized by the occurrence along the top of the flow of crude pillows, chilled rinds, and intermixed baked siltstone.

The Deschutes Formation overlies the Simtustus Formation with angular and erosional unconformity. In the Gateway area, the Simtustus Formation dips 5° to the southwest, as does the Columbia River Basalt Group (Hayman, 1983), while the Deschutes Formation dips less than 1° southwestward. East of Gateway, there is at least 30 m of relief on the contact between the two formations (Figure 2). West of the Deschutes River and along the eastern margin of the basin, the Deschutes Formation rests directly on the John Day Formation or Columbia River Basalt Group, indicating that either the Simtustus Formation was never deposited or that it was removed by erosion before Deschutes Formation deposition commenced. Reverse faults near the east abutment of Pelton Dam offset the Columbia River Basalt Group and the upper and lower Simtustus Formation by the same amount but do not affect the Deschutes Formation (Figure 3).

The age of the Simtustus Formation is inferred from isotopic dates and paleontological studies. The lowest Prineville chemical-type basalt flow at Pelton Dam has been dated by $^{40}Ar/^{39}Ar$ method at 15.7 ± 0.1 m.y. B.P. (L.W. Snee, personal communication, 1985). This date is consistent with correlation of the flows at Pelton Dam to similar Prineville chemical-type basalts intercalated with low-MgO Grande Ronde Basalt north

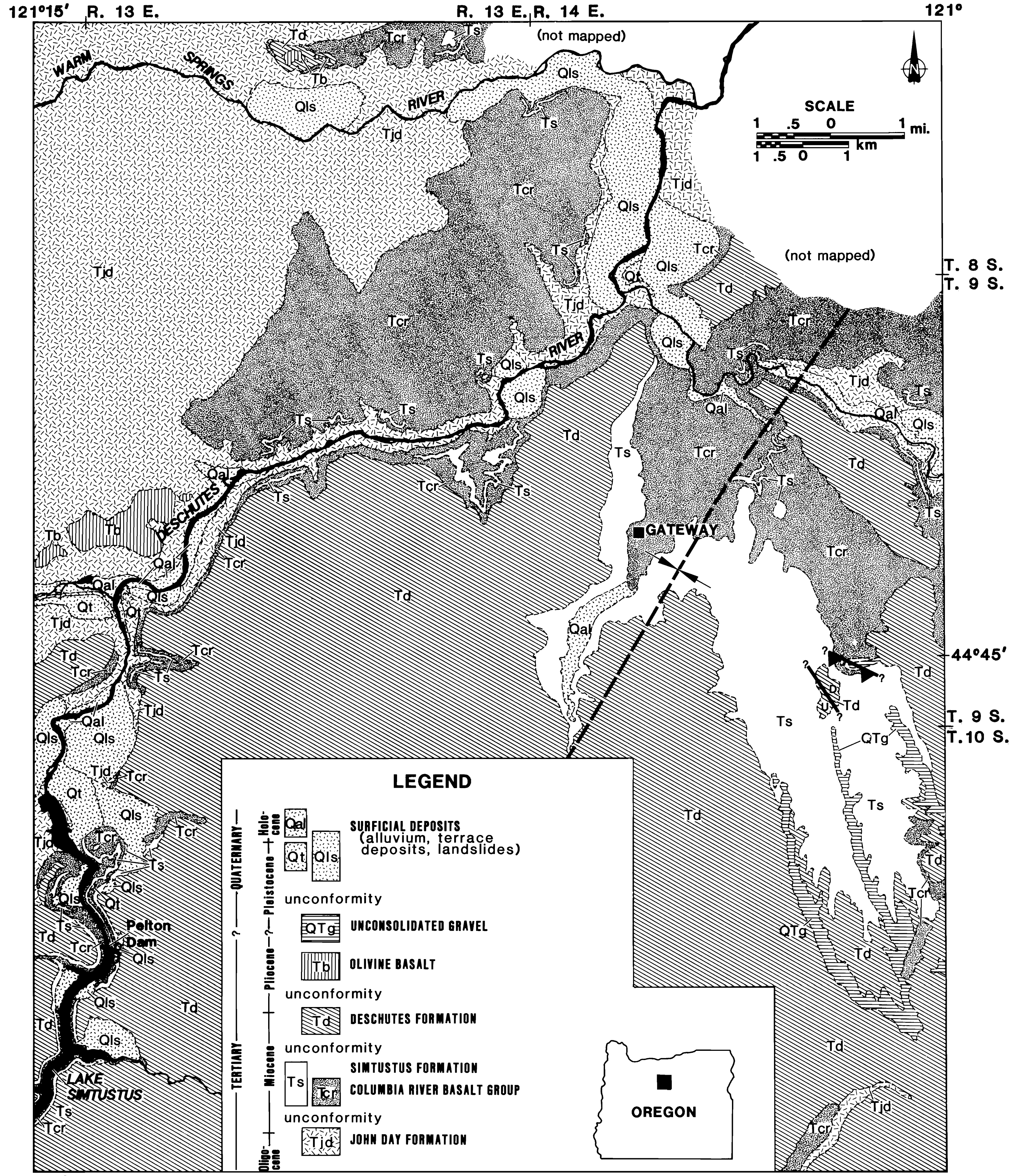

Figure 3. Geologic map of the northern Deschutes basin.

of the Deschutes basin (Nathan and Fruchter, 1974; Smith, 1986). The isotopic date is also consistent with the occurrence of the middle Miocene Pelton flora of Ashwill (1983), which is located in the lower Simtustus Formation (not in the Deschutes Formation, as reported by Ashwill, 1983). The date of the top of the Simtustus Formation, as it is preserved, is uncertain. However, less than 30 m separates Downs' (1956) pre-12-m.y. B.P. faunal localities in the upper Simtustus Formation from the unconformity with the Deschutes Formation. The 7.6-m.y.-old Pelton basalt member of the Deschutes Formation occurs near the unconformity (Figure 2; cover photo). This suggests that the preserved Simtustus Formation is entirely middle Miocene in age (12 to 15.5 m.y.) and that a hiatus of 5 m.y. or more is represented by the Simtustus-Deschutes unconformity.

FACIES ANALYSIS OF THE SIMTUSTUS FORMATION

Typical vertical sequences of lithofacies in the Simtustus Formation are represented in the measured sections (Figure 2). Two facies associations are apparent in these sections: (1) cross-bedded sandstone with minor mudstone and (2) massive mudstone and fine-grained sandstone.

The cross-bedded sandstone and minor mudstone facies are arranged in fining-upward cycles 1 to 6 m thick, averaging 2.5 m thick (Figure 4). These sequences commence with trough cross-bedded, coarse-grained, pumice-bearing sandstone or massive to horizontally stratified pebble conglomerate. The height of cross-bed sets generally decreases and the abundance of pumice lapilli increases upward in a cycle, sometimes passing into ripple cross-laminated, fine- to medium-grained sandstone. Paleocurrent directions measured from cross-bedding in both the lower and upper Simtustus Formation vary widely from N. 20° W. to N. 75° E., with mean orientations at individual locations in northeastward directions. The upper portion of each cycle is massive, light-tan, blocky jointed, fine-grained sandstone and mudstone with dispersed, rounded, pumice lapilli. This fine-grained interval frequently contains bone fragments, partial leaf and stem impressions, and rare permineralized root molds. These massive sedimentary units are interpreted as bioturbated overbank deposits.

The massive mudstone and fine-grained sandstone facies are well exposed southeast and southwest of Gateway. These deposits have much in common with inferred overbank deposits capping cycles in sandstone-dominated deposits. They are light-tan, massive, blocky jointed mudstone and fine-grained sandstone with beds of pumice lapilli interrupted by burrows and abundant lapilli dispersed through the sediment (Figures 5 and 6). Because of poor sorting, massive character, dominance of pyroclastic fragments, and dispersed pumice lapilli, these sediments closely resemble ignimbrites. However, close examination shows rare discontinuous sedimentary structures, epiclastic sandstone lenses lacking finer grained ash, and gradational lower contacts with cross-bedded sandstones. These features argue against these units being ignimbrites and suggest that the massive, poorly sorted character reflects homogenization and mixing of pyroclastic sediment by pedogenic processes. Exposures on Gateway Grade, southwest of the village, and along U.S. 97 suggest that these lithologies are organized into crude fining-upward cycles, 0.5 to 2 m thick, in which the abundance of lapilli and grain size of enclosing sediment decreases upward (Figure 5a). Bone fragments are very common, and opal-replaced *Celtis* (hackberry) endocarps are ubiquitous (Figure 6). In some localities, remnant sedimentary structures within the generally massive units are represented by thin-bedded, ripple-cross-laminated, fine-grained sandstones (Figure 5a) and plane-laminated siltstones and claystones. Clastic dikes, 1 to 2 cm wide, are filled with vertically laminated mudstone and occur in several exposures near Gateway (Figure 5b).

Volcanic debris-flow deposits have also been recognized in the Simtustus Formation. They are massive, 1 to 3 m thick, and dominated by pebble- to cobble-size clasts supported in a matrix of sand- and mud-size material. One deposit occurs north of Pelton Dam in the type section. Another occurs south and east of Gateway and contains flame structures and clastic dikes of underlying tuffaceous mudstone at its base resulting from rapid loading of saturated sediments. This latter unit thickens eastward from 1.5 m thick near Gateway to 3 m thick in Old Maids Canyon, 5 km southeast of Gateway.

The fining-upward cycles of cross-bedded sandstone to massive mudstone and highly variable paleocurrent directions are suggestive of sedimentation on point bars by meandering streams (Allen, 1964, 1970). Cross-bedded sandstone represents deposition by subaqueous dunes in the river channel and, as the channel migrated, was succeeded by fine-grained overbank

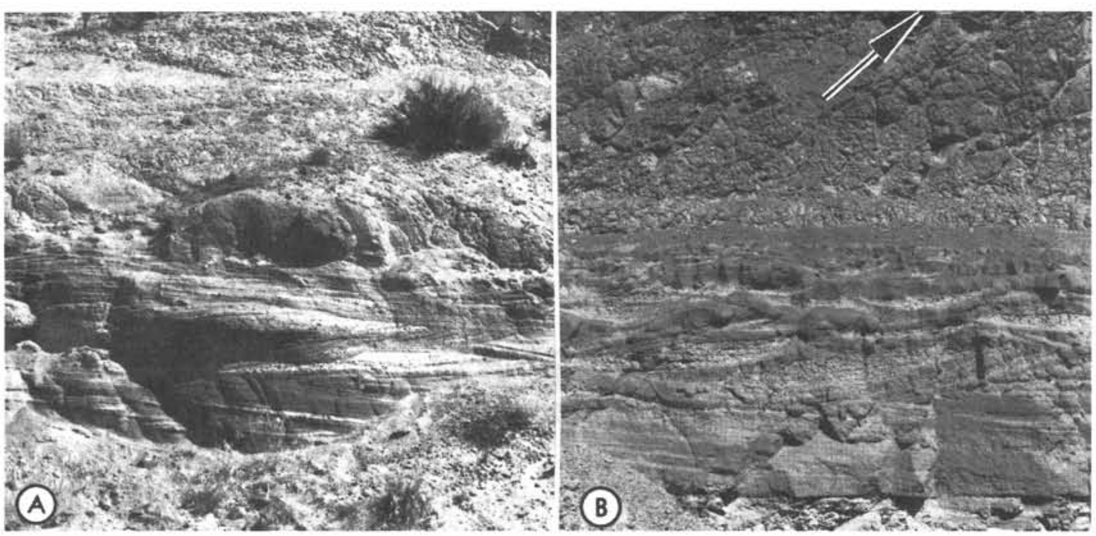

Figure 4. Upward-fining fluvial cycles in the Simtustus Formation. Each cycle commences with trough cross-bedded sandstone and grades upward into massive, blocky jointed mudstone. (a) Upper Simtustus Formation, Clark Drive, 1.0 km south of Gateway. (b) Lower Simtustus Formation at Pelton Dam. Arrow points to air-fall tuff within tuffaceous mudstone.

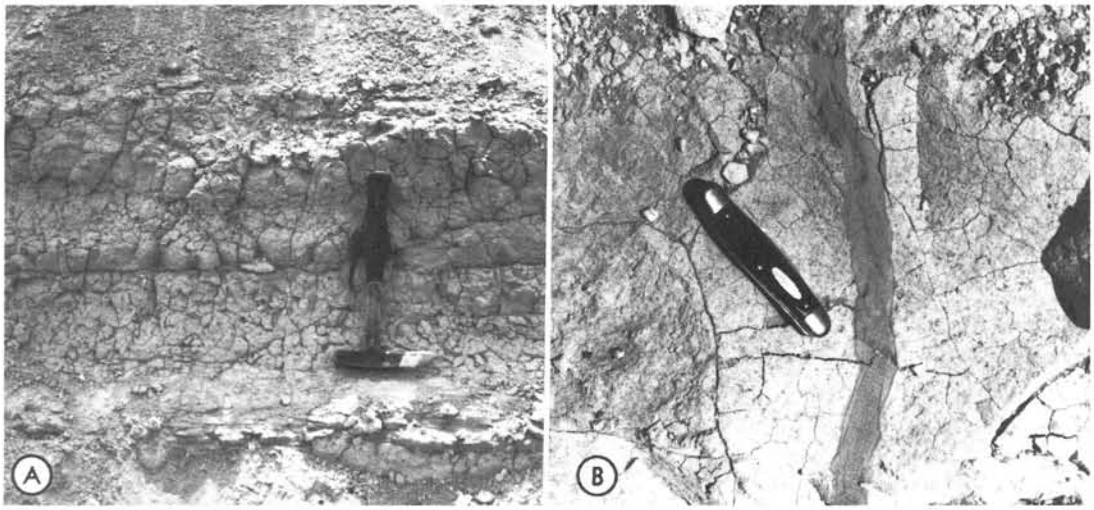

Figure 5. Outcrop photos of fine-grained sandstone and mudstone facies association. (a) Thin fining-upward sequences of ripple cross-laminated sandstone to massive mudstone; roadcut on U.S. 97, east of Gateway. (b) Clastic dike of vertically laminated mudstone cutting massive mudstone; roadcut on Gateway Grade, southwest of Gateway.

sedimentation.

The massive fine-grained sandstone- and mudstone-facies association probably represents flood-plain deposition adjacent to, but beyond the extent of lateral migration of, a river channel. This relationship is suggested by (1) bioturbation indicated by the massive character of these facies with occasional remnant structures; (2) the abundant fossil remains; (3) similarity to fine-grained upper parts of preserved point-bar facies; and (4) thickness in excess of 20 m without intervening cross-bedded sandstone or conglomerate.

PETROGRAPHY OF THE SIMTUSTUS FORMATION

Petrographic examination indicates that most Simtustus sandstones are feldspathic volcanic arenites with subordinate volcanic plagioclase arkoses and volcanic arenites (classification of Folk, 1968) and contain nearly equal proportions of pyroclastic and epiclastic volcanic fragments. Quartz and sanidine compose less than 1 volume percent of the sandstones. Heavy minerals, mostly pyroxene, hornblende, and iron-titanium oxides, are present to as much as 5 volume percent and usually display alteration rims of hematite and unidentified clay minerals.

The lithic fraction is all volcanic and, in most sandstones, consists of 50 to 75 percent slightly to highly altered, light-brown to colorless glass of coarse ash to lapilli size. Altered lapilli appear green, lavender, and pink in hand sample. This sediment was probably reworked from air-fall pyroclastics erupted in the Cascade Range and is primarily of dacitic composition (G. Hayman, personal communication, 1983). Rarely, as much as 50 percent or more of the lithic fragments are epiclastic volcanic grains. The mineralogy and texture of the epiclastic grains suggest that most are basaltic andesites and andesites derived from the Cascades, with a subordinate contribution from the interbedded Columbia River basalt (the Prineville chemical type is characterized by an abundance of groundmass apatite, making it petrographically distinct from Cascade basaltic rocks). As much as 10 percent of some sandstones consists of devitrified rhyolite grains that were probably eroded from John Day Formation rhyolite domes and ignimbrites, which likewise are the probable source of the minor quartz and sanidine. True rhyolites, with phenocrystic quartz and sanidine, are virtually unknown in the Oregon Cascades (Priest and others, 1983).

The sandstones are poorly to well cemented by opaline silica and unidentified clay minerals. Scanning electron microscope examination of one lower Simtustus sandstone also disclosed the occurrence of an unidentified, acicular zeolite. Green cryptocrystalline silica, known to local rock collectors as "wascoite," forms concretions up to 25 cm across in the lower Simtustus and also occurs as amygdules within the lower Columbia River basalt flow.

MIDDLE MIOCENE DESCHUTES BASIN PALEOGEOGRAPHY

Only a general paleogeographic picture can be constructed for the Deschutes basin during Simtustus Formation deposition because (1) exposure is restricted to the area north of Madras; (2) the main outcrop areas at Lake Simtustus and in the Gateway region are separated by an intervening area of no exposure (Figure 3); and (3) an unknown volume of the unit was removed by pre-Deschutes erosion.

The Columbia River basalt flows largely buried a terrain with erosional relief exceeding 100 m. The distribution of the lower flow was strongly controlled by the paleotopography (Smith, 1986), and lower Simtustus deposition was also largely restricted to the location of pre-existing valleys. The combined thickness of the lower basalt flow and the lower Simtustus sediment was sufficient to allow the upper flow to cover most remaining hills to produce a gently sloping plain, almost 20 km wide, on which upper Simtustus deposition occurred. Because lower Simtustus streams were confined to topographic lows, the thick flood-plain facies association is not as well represented as in the upper Simtustus Formation, where there was no confinement.

Fluvial aggradation to produce the Simtustus Formation may largely have been the result of drainage disruption by Columbia River Basalt Group lava flows (Smith, 1984). Notably, there is no record of middle Miocene deposition prior to eruption of the lowest basalt flow in the Deschutes basin, but, as discussed previously, deposition did probably commence soon after the emplacement of this flow. The two lava flows have a combined thickness of 15 m to 150 m and buried most of the paleotopography to produce a low-gradient surface on which Simtustus streams flowed. This abrupt modification of gradients could produce aggradation in a previously nondepositional system. Expected sedimentation under these conditions would be rela-

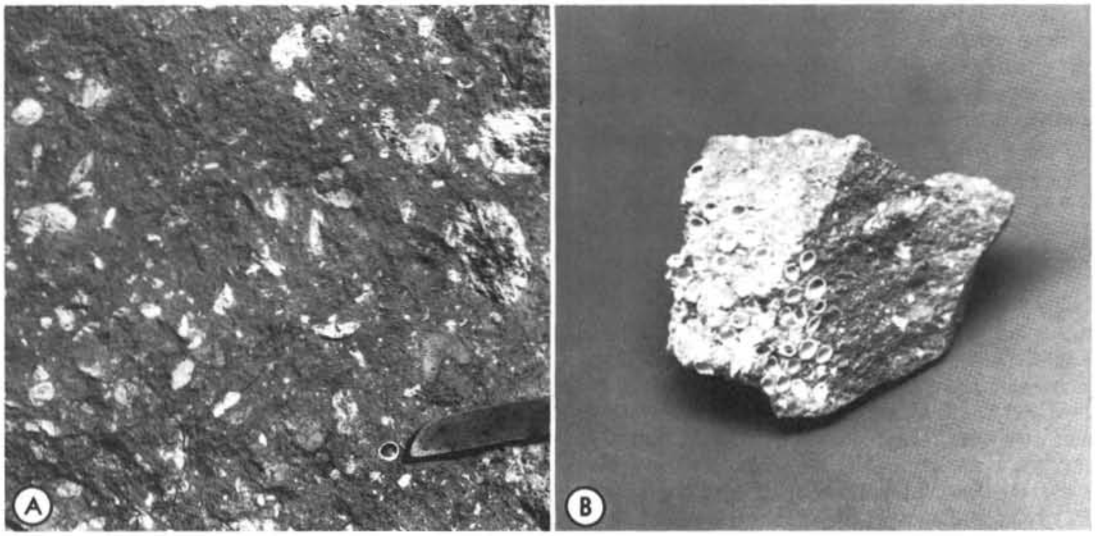

Figure 6. Photographs showing Celtis *endocarps in the Simtustus Formation. (a) Lapilli-bearing mudstone with scattered endocarps; most prominent endocarp is at tip of knife blade. (b) Hand sample of tuffaceous mudstone with numerous endocarps. Sample is 8 cm across.*

tively fine grained because of decreased competence and would include broad flood-plain deposits such as those seen in the Simtustus Formation.

Aggradation would continue until a pause of sufficient duration in basaltic volcanism occurred to allow uninhibited downcutting by the rivers. Over 200,000 km^3 of basalt of the Grande Ronde Basalt was erupted onto the Columbia Plateau between about 17.0 and 15.5 m.y. B.P. (Swanson and others, 1979). Basalt flows of the upper Grande Ronde Basalt, Wanapum Basalt (16.5 to 14.5 m.y. B.P.), and Saddle Mountains Basalt (13.5 to 6 m.y. B.P.) of the Columbia River Basalt Group are restricted north of the Deschutes basin. Although only the two flows of Prineville chemical type occur within the basin, the contemporaneous Grande Ronde Basalt inundated the ancestral Columbia and Deschutes Rivers north and downstream of the Deschutes basin, severely disrupting drainage to produce lakes adjacent to the thickening basalt plateau and raised local base level (Fecht and others, 1985).

Degradation in the Deschutes basin could commence only after headward erosion by the ancestral Columbia River progressed far enough eastward to integrate these lakes and the ancestral Deschutes River drainage. It is not clear where the confluence of the ancestral Deschutes and Columbia Rivers was at this time, but basalt distribution maps (Swanson and others, 1979) and study of the evolution of the Columbia River drainage (Anderson and Vogt, in preparation) suggest that headward incision of the ancestral streams significantly east of the Cascade Range did not occur until sometime between 14 and 12 m.y. B.P. Aggradation in the ancestral Deschutes River, imposed by flood basalt volcanism, would then extend over the period from about 16 m.y. B.P. to sometime before 12 m.y. B.P., which is consistent with available information for the age of the Simtustus Formation.

The general northeasterly course for the Deschutes River during Simtustus time, indicated by paleocurrent analysis and distribution of the interstratified basalt flows, reflects the topographic influence of the Mutton Mountains to produce an eastward deflection in the generally north-flowing river. This influence is also indicated by the Deschutes Formation paleodrainage (Smith, 1986) and modern drainage. The Mutton Mountains are a broad anticlinal uplift of east to northeast trend. However, much of the topographic relief is constructional, not structural, and is defined by a north-northeast-trending line of John Day Formation rhyolite domes. Uplift of the anticline commenced prior to the emplacement of the Columbia River basalt flows, as indicated by the underlying angular unconformity with the John Day Formation. The Prineville chemical-type basalts lapped onto the south flank of the highland, progressed around its eastern end, and spread out again to the north. Contemporary Grande Ronde Basalt flows that were erupted in northeastern Oregon and southeastern Washington onlapped the north flank of the Mutton Mountains, and some of the youngest flows extended a short distance southward around the east end of the anticline (Smith, 1986). Further uplift resulted in the angular unconformity between the Deschutes and Simtustus Formations. A broad, northeast-southwest-trending syncline with opposing dips up to 12° in the basalt is developed in the pre-Deschutes Formation rocks in the northern part of the basin (Figure 2). This syncline, south of the Mutton Mountains anticline, has apparently controlled the location of the Deschutes River since at least middle Miocene time.

RELATIONSHIP TO CASCADE VOLCANISM

Although Simtustus Formation deposition probably resulted from drainage disruption by the Columbia River basalt lavas, most of the sediment within the formation is of Cascade Range provenance. The late Western Cascade volcanic episode (18 to 9 m.y. B.P.) of Priest and others (1983) is represented in the central Oregon Western Cascades by basaltic andesite and andesite lavas with subordinate dacitic pyroclastic units (Priest and others, 1983). The Simtustus Formation, composed of primary and reworked dacitic and rhyodacitic pyroclastic material and epiclastic fragments of basaltic andesite and hornblende or pyroxene andesite, is a distal reflection of this volcanic episode.

The ratio of pyroclastic to basaltic andesite and andesite epiclastic material in the Simtustus Formation is about 2:1, although Priest and others (1983) indicate that pyroclastic material is subordinate to other lithologies in the proximal Western Cascades, which are 75 km to the west. This difference illustrates the hazards of characterizing volcanism on the basis of distal sediment composition. Pyroclastic debris is more widespread and more easily eroded than are lava flows and therefore dominates over epiclastic grains among transported sediment. However, there are also problems in assuming that proximal volcanic rocks accurately reflect the eruptive behavior of a volcanic episode. Pyroclastic material is usually unconsolidated, easily removed from steep slopes and high-gradient stream valleys typical of the proximal setting of mature volcanic arcs, and, hence, not preserved there. These characteristics tend to produce relative enrichment of pyroclastic sediment in distal depositional basins when compared with the record of pyroclastic volcanism in the source areas. It is also possible that some of the tuffaceous material in the Simtustus Formation was derived from erosion of the widespread dacitic air-fall deposits of the John Day Formation (Robinson and others, 1984).

REGIONAL STRATIGRAPHIC CORRELATION

The Simtustus Formation is the first well-studied sedimentary unit in Oregon that is interbedded with the Columbia River Basalt Group. In eastern Oregon, sedimentary interbeds within the Columbia River Basalt Group and age-equivalent Strawberry Volcanics have been recognized for their fossil floras but have generally not been named. These include sedimentary material hosting the Blue Mountains flora of Chaney and Axelrod (1959) in Grant County, 220 km east of the Deschutes basin, and the Sparta flora of Hoxie (1965) northeast of Baker, 300 km east of the Deschutes basin. Although these units are roughly contemporaneous in age and share floral elements with the Simtustus Formation, their distribution and sedimentological characteristics remain unstudied.

The Simtustus Formation is also correlative with the Mascall Formation of Merriam (1901) and Merriam and others (1925). The Mascall Formation was defined (Merriam, 1901) as a dominantly lacustrine sequence in the John Day valley, 125 km east of the Deschutes basin, where it is conformable upon and locally interfingers with the Picture Gorge Basalt of the Columbia River Basalt Group. The Picture Gorge Basalt is elsewhere intercalated with the Grande Ronde Basalt (Nathan and Fruchter, 1974). The Mascall Formation is overlain with angular unconformity by the Rattlesnake Formation of Merriam (1901) and Enlows (1976) (redefined as the Rattlesnake Ash-flow Tuff and unnamed conglomerate by Walker[1979]), which is dated at about 6.6 m.y. B.P. (Enlows, 1976). The Rattlesnake ignimbrite is also interbedded with the Deschutes Formation in the eastern Deschutes basin (Smith and others, 1984; Smith, 1986). The Simtustus and Mascall Formations thus share a similar structural and stratigraphic position relative to the Columbia River Basalt Group and overlying upper Miocene rocks and also share a similar vertebrate fauna (Downs, 1956).

Unnamed sedimentary rocks with Mascall faunal components (Downs, 1956) or similar stratigraphic position occur at several localities east of the Deschutes basin (Walker, 1977) and are probably generally correlative with the Simtustus Formation. Until more sedimentologic and stratigraphic work is done, it seems prudent to restrict the name Mascall Formation to the dominantly lacustrine, pyroclastic sediments of the John Day basin, to restrict Simtustus Formation to the dominantly fluvial, mixed pyroclastic and epiclastic sediments of the Deschutes basin, and to leave other middle Miocene volcaniclastic rocks unassigned at this time.

The absence of rocks of lacustrine origin within the Simtustus Formation indicates that the Deschutes basin was not a closed basin at that time. Therefore, deposits of the aggrading fluvial system with characteristics similar to the Simtustus Formation can be expected to occur farther north and have been recognized during reconnaissance investigations. In Cow Canyon, 30 km northeast of Madras, fluvially deposited sediments that are lithologically identical to the Simtustus Formation occur between a Prineville chemical-type basalt flow and a high-MgO Grande Ronde Basalt flow, probably from the upper half of the Grande Ronde section (Swanson and others, 1979). Similar interbeds occur with Prineville chemical-type and low-MgO Grande Ronde flows on the north flank of the Mutton Mountains; one of these interbeds hosts the Foreman Point flora of Ashwill (1983). In Butler Canyon on Tygh Ridge, 70 km north of Madras, two Prineville chemical-type flows, believed to be the same two as in the Deschutes basin (Smith, 1986), are separated by four low-MgO Grande Ronde Basalt flows (Nathan and Fruchter, 1974). Two sedimentary interbeds lithologically similar to the Simtustus Formation occur within this interval and are correlative to the lower Simtustus in the Deschutes basin. Similar tuffaceous sediments occur as interbeds higher in the Columbia River Basalt Group section on Tygh Ridge and also conformably above the basalt. The sediments conformable upon the basalt (mapped as Ellensburg Formation by Waters, 1968b) are lithologically distinct from the overlying sediments of the Dalles Formation of Waters (1968b) or Tygh Valley Formation of Farooqui and others (1981a) and are separated from them by a 40° angular unconformity. The sediments conformable upon the basalt should not be included in the Tygh Valley Formation of Farooqui and others (1981a). Thin, laminated mudstones occur between Grande Ronde flows on the north flank of Tygh Ridge and probably represent the lakes into which the ancestral Deschutes River flowed. Formal stratigraphic designation of these sedimentary units should await more detailed study, but the observations described above indicate northward continuation of the Simtustus Formation lithosome and suggest that the Simtustus Formation overlying the Prineville chemical-type lavas in the Deschutes basin is intercalated with younger Columbia River basalt flows to the north.

Beyond north-central Oregon, the Simtustus Formation is correlative to middle Miocene sedimentary units that are interbedded with the Columbia River Basalt Group in Washington and with others in the Basin and Range province in southeastern Oregon. The Ellensburg Formation and Latah Formation are interbedded with and locally overlie the Columbia River Basalt Group in central Washington and northeastern Washington and adjacent Idaho (Swanson and others, 1979). The Ellensburg Formation, as redefined by Swanson and others (1979) to include all sedimentary interbeds within the basalt and sediments above the basalt in the western Columbia Plateau in Washington, is a lithologically diverse unit of volcanogenic and arkosic fluvial and lacustrine sediments (Mackin, 1961; Schmincke, 1964) that locally accumulated to great thickness in basins of the Yakima fold belt. The Ellensburg Formation is also interbedded with and overlies Wanapum and Saddle Mountains Basalt and contains a Hemphillian fauna near Yakima (Martin, 1979); therefore only the lower part is correlative with the Simtustus Formation. The Latah Formation is composed of fine-grained arkosic sediments primarily deposited in lakes (Pardee and Bryan, 1926) that formed along the eastern margin of the basalt plateau, presumably because of drainage disruption by the lava flows.

Based on similar fauna and flora, the Simtustus Formation is also correlative, in part or whole, with the Sucker Creek Formation, Deer Butte Formation, Drip Spring Formation, and Butte Creek Volcanic Sandstone and interbedded basalts, rhyolites and ignimbrites in southeastern Oregon of Kittleman and others (1965). These volcanogenic and arkosic sediments filled fault-bounded basins in the Basin and Range province.

CONCLUSIONS

The Tertiary nonmarine sedimentary rocks of central and eastern Oregon require detailed study to obtain useful stratigraphic and sedimentologic information necessary to evaluate the stratigraphic nomenclature, paleogeography, and tectonic development of the region. In over eighty years of geologic endeavor in the Deschutes basin, almost a dozen workers failed to recognize the occurrence of an unconformity within the sedimentary rocks overlying the Columbia River Basalt Group. This oversight reflects the reconnaissance nature typical of most stratigraphic studies in the eastern two-thirds of the state. Detailed stratigraphic study indicates that this unconformity, representing a depositional hiatus of 5 m.y. or more, separates two lithologically distinct volcaniclastic sequences with largely Cascade provenance, the newly defined Simtustus Formation, and revised Deschutes Formation.

The Simtustus Formation represents channel and flood-plain deposition by low-gradient, mixed-load, possibly highly sinuous streams. Based upon compelling circumstantial evidence, aggradation primarily resulted from drainage disruption and gradient diminishment by basalt flows of the Columbia River Basalt Group with which the Simtustus Formation is demonstrably contemporaneous. Basin analysis of the Simtustus Formation and distribution of intercalated Grande Ronde Basalt (Prineville chemical type) suggest that uplift of the Mutton Mountains had commenced prior to the middle Miocene and has influenced the regional drainage pattern since that time.

The Simtustus Formation is the first well-studied sedimentary unit in Oregon that interfingers with the Columbia River Basalt Group. Other sedimentary units interbedded with these basalts in Oregon are unnamed, with the exception of the Mascall Formation, and known only for their faunal and floral constituents. The sedimentary rocks interbedded with the Columbia River Basalt Group on most of the Washington portion of the Columbia Plateau are assigned to the Ellensburg or Latah Formation and are lithologically distinct from the only partly age-equivalent rocks in the Deschutes basin, warranting use of a separate name. Following the practice of Schmincke (1964) and Swanson and others (1979) in Washington, sediment interbedded with the Columbia River basalt in the Deschutes basin is assigned to the overlying Simtustus Formation because it cannot be lithologically distinguished from the volcaniclastic rocks conformable above the basalt.

Subdivision of sedimentary units deposited contemporaneously with the Columbia River Basalt Group on the basis of stratigraphic position relative to the named basalt members is not perpetuated because of potential ambiguity when definitive basalts do not occur in a sedimentary sequence. The author hopes that future stratigraphic assignments of interbedded sedimentary units will be based upon the lithostratigraphic character of the sedimentary rocks alone, regardless of the basalts with which they are associated. Relative to this problem, it is notable that while most of the type Simtustus Formation overlies the Columbia River Basalt Group in the Deschutes basin, at the plateau margin, it probably interfingers with younger flows northward toward the plateau interior. Reconnaissance observations suggest continuation of the Simtustus Formation at least as far north as Tygh Ridge, but stratigraphic assignments of volcanogenic sedimentary rocks interbedded with the Columbia River basalt north of the Deschutes basin is left for future detailed work.

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Atlas of West Coast seafloor released

An atlas of the U.S. deep-water seafloor off the West Coast, the first extensive seafloor atlas of its kind, has been published by the U.S. Geological Survey (USGS).

The atlas represents the marriage of unique sonar technology developed by the British Institute of Oceanographic Sciences (IOS) and computer-enhanced mapping techniques developed by the U.S. Geological Survey as part of the U.S. space program. The 152-page atlas will help delineate potential energy and mineral resource targets and also reveals dozens of previously unmapped submarine volcanoes, landslides, faults, and other features.

The sonar system -- called GLORIA -- developed by IOS is capable of mapping up to 10,500 square miles a day, an area roughly equivalent to the size of New Jersey or Maryland. The sonar mosaic maps published in the atlas were enhanced through cartographic and computer techniques developed by the USGS as part of the space program effort to map the geology of the moon and the planets. Opposite each mosaic sheet in the atlas is another sheet at the same scale (1:500,000; one inch equals 8 miles) showing some of the preliminary geologic interpretation and bathymetry. Two other sections in the atlas provide a three-dimensional glimpse of the seafloor geology using seismic reflection and residual magnetic anomaly data collected at the same time as the sonar data.

Copies of the atlas, titled "Atlas of the Exclusive Economic Zone, Western Conterminous United States," and published as USGS Miscellaneous Investigations Series I-1792, may be purchased for $45 each from the Western Distribution Branch, U.S. Geological Survey, Box 25286, Federal Center, Denver, Colo. 80225, telephone (303) 236-7477. When ordering by mail, please include both the atlas number (I-1792) and title and check or money order payable to Department of the Interior-USGS.

— *USGS press release*

ABSTRACTS

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.

PALEOMAGNETISM, ROCK MAGNETISM, AND DIAGENESIS IN HEMIPELAGIC SEDIMENTS FROM THE NORTHEAST PACIFIC OCEAN AND THE GULF OF CALIFORNIA, by Robert Karlin (Ph.D., Oregon State University, 1984 [dissertation compl. 1983])

Downcore magnetic profiles from undisturbed Kasten cores taken in rapidly deposited laminated sediments from the Gulf of California and in bioturbated hemipelagic muds on the Oregon continental slope give apparently reliable directions, but show dramatic decreases in the intensities of natural (NRM) and artificial (ARM, IRM) remanences with depth. Downcore porewater and solid sulfur analyses show concave-down decreases in porewater sulfate and systematic increases in pyrite and metastable monosulfides. The maximum curvature of the sulfide profiles occurs directly below the high magnetization zone. Combined with other compositional and mineralogic analyses, these data suggest that, due to oxidative decomposition of organic matter, magnetites and other iron oxides become progressively reduced and subsequently sulfidized and pyritized with depth. Iron reduction seems to occur prior to sulfide formation. Changes in magnetic stability parameters are consistent with selective dissolution of the finer sized grains causing downcore coarsening of the magnetic fraction.

Paleomagnetic directions from the Oregon sediments show exceptional directional stability and provide a detailed record of geomagnetic secular variation for the past 3,000 years. When compared to secular variation studies from other regions, directional fluctuations show good coherence and time delays consistent with a constant westward drift having a periodicity of 1,200 years which has continued for at least the last 3,000 years. A maximum correlation analysis with a zonal drift model of the present field lends support to this hypothesis.

Paleomagnetic measurements on a 152-m sedimentary section taken with a Hydraulic Piston Corer at DSDP Site 480 in the Gulf of California yield an almost continuous secular variation record for the past 200-300 Ky. Initial results show no major zones of reversed polarity, and the core and site mean inclinations are not significantly different than the expected geocentric axial dipole inclination. The similarity of mean inclinations in laminated, homogeneous, and mottled sediment lithologies suggests that remanence was acquired below the active zone of bioturbation.

SEDIMENTATION, STRUCTURE, AND TECTONICS OF THE UMPQUA GROUP (PALEOCENE TO EARLY EOCENE), SOUTHWESTERN OREGON, by Paul Thomas Ryberg (Ph.D., University of Arizona, 1984)

A major change in sedimentary and structural style occurs in Eocene strata exposed along the southern margin of the Oregon Coast Range. Lithofacies of the early Tertiary Umpqua Group have been described, mapped, and assigned to likely depositional environments. Submarine fan and slope facies (upper Roseburg Formation) overlie Paleocene basaltic basement rocks to the north, whereas fluvial, deltaic, and shallow-marine facies (Lookingglass Formation) overlie Franciscan-equivalent strata to the south along the flank of the Klamath Mountains. These two depositional systems are gradational into one another, and were prograding northwestward until about 52 m.y. B.P. Means of clast compositions from sandstones and conglomerates from both the Roseburg and Lookingglass Formations suggest derivation from identical recycled orogen or arc-continent collision sources in the Klamath Mountains.

Change from Klamath-parallel to more north-south structural trends is well displayed within early Eocene strata of the Umpqua Group. Five major fault systems involve lower Umpqua (Roseburg and Lookingglass) strata and were active while deposition was taking place. All these faults ceased to be active at about 52-50 m.y. B.P. and are overlapped by the middle Eocene Tyee Formation. Regional strain analysis indicates more than 20 percent shortening by right-lateral convergence during early Eocene time.

The structural style and syntectonic deformation of marine slope facies suggest deposition in an active subduction complex until about 52 m.y. B.P. Structural trends in the Southern Oregon Coast Range parallel those in the adjacent Klamath Mountains until the end of the early Eocene. At 52-50 m.y. B.P., subduction apparently ceased as incoming seamounts clogged the trench and may have jumped to an outboard position near the present-day coastline. In middle Eocene time, the newly developed forearc region rapidly filled with sediments from a much sandier depositional system.

Paleomagnetic studies of relatively undeformed Tyee forearc strata indicate as much clockwise rotation as the much more deformed, underlying volcanic basement of the Oregon Coast Range. Rotation of the Oregon Coast Range as a single crustal block must have occurred after, rather than during, seamount accretion to the continental margin, which was essentially complete by 52 m.y. B.P.

GEOLOGY OF THE NORTHEAST ONE-QUARTER OF THE PRINEVILLE QUADRANGLE, NORTH-CENTRAL OREGON, by Neil J. Bingert (M.S., Oregon State University, 1984)

The project area is located in north-central Oregon approximately 8 km north of the city of Prineville. The most widespread geologic unit found in the project area is the Clarno Formation. The Clarno Formation has been subdivided into two main mappable units: a lower member and an upper member. This division is based on the occurrence of a thick, extensive saprolite between the two members. The lower member is composed of coarsely porphyritic domes and flows of rhyodacitic to andesitic composition. All of the lower member lavas contain phenocrysts of plagioclase, clinopyroxene, orthopyroxene, and quartz. Hornblende is an additional phase found in the rhyodacites. The upper member contains flows and domes of fine-grained nonporphyritic to coarsely porphyritic lavas of predominantly andesitic composition. Basalts and basaltic andesites are subordinate. The major phenocrystic phases found in most upper-member lavas include plagioclase, clinopyroxene, and orthopyroxene. In addition, several contain phenocrysts of quartz, olivine, or hornblende. The upper member has been further subdivided by separately mapping hornblende-bearing dacites and rocks of rhyodacitic composition. The hornblende-bearing dacites occur as a chain of east-west trending domes with associated short, thick, autobrecciated flows. Rocks of rhyodacitic composition within the upper member include two domes and one extensive xenolith-bearing flow.

In addition to the Clarno Formation, the project area also contains outcrops of John Day Formation, two units of undetermined age, and various Quaternary alluvium deposits. The John Day Formation has been subdivided into two mappable units including a welded ash-flow tuff and exposures of tuffaceous claystones. The rocks of undetermined age include a welded ash-flow tuff and an olivine basalt flow.

The entire project area lies on the southern limb of the Blue Mountain anticline. All of the dips in the area are gentle. Only two faults have been positively identified in the area. Both trend east-west and appear to be of the normal type with only minor displacement.

STRUCTURAL GEOLOGY OF THE RASTUS MOUNTAIN AREA, EAST-CENTRAL OREGON, by Kenneth R. Engh (M.S, Washington State University, 1984)

The Rastus Mountain area lies within the Ironside Mountain inlier of eastern Oregon. The inlier contains rocks of Mesozoic age and is surrounded by a Tertiary volcanic and sedimentary cover. Pre-Tertiary rocks in the Rastus Mountain area are represented by the Early to Middle Jurassic Weatherby Formation.

The Weatherby Formation has been tightly folded into northwest- to southeast-trending asymmetric chevron-shaped folds with a pervasive axial planar cleavage. The folds have a 28° interlimb angle, subhorizontal axes, and axial planes that dip approximately 70°/71° SE.

The Weatherby has undergone shortening of at least 35 percent perpendicular to the axial plane of the folds. Precise determination of the amount of strain is complicated by pressure solution which played a large role in the formation of the axial planar cleavage.

Deformation of the Weatherby probably occurred in the Late Jurassic, marking the end of deposition in the basin.

The Weatherby Formation consists dominantly of calcareous gravity flow deposits containing abundant volcanic rock fragments. These rocks were probably deposited in a forearc basin and are allochthonous. Approximately 750 m of the Weatherby Formation is exposed in the Rastus Mountain area.

The Weatherby Formation has been intruded by granodioritic to granitic stocks and dikes. The dikes are surrounded by a 500-m contact metamorphic aureole. Rock types within the aureole include skarn, marble, and hornfels. □

OIL AND GAS NEWS

Oregon Natural Gas begins preparation for gas storage

In late April, Oregon Natural Gas Development Corp. began preparation for gas storage by perforating an existing well in the Bruer Pool. The well, Columbia County 32-10, was drilled in 1981 by Reichhold Energy in sec. 10, T. 6 N., R. 5 W., as a deep test below the pool. It has been suspended since that time. By perforating the Clark and Wilson storage zone, the present operator now has made a fourth well available for storage in the pool. Additional storage and monitor wells will be drilled in the future.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
357	Hutchins & Marrs Georgia Pacific 2 011-00023	NE¼ sec. 14 T. 30 S., R. 10 W. Coos County	Application; 6,000.
358	Damon Petroleum Stauffer Farms 35-1 047-00020	NW¼ sec. 35 T. 4 S., R. 1 W. Marion County	Application; 2,800.
359	ARCO Crown Zellerbach 21-22 009-00196	NW¼ sec. 22 T. 5 N., R. 4 W. Columbia County	Application; 3,315.
360	ARCO Columbia County 42-8 009-00197	NE¼ sec. 8 T. 5 N., R. 5 W. Columbia County	Application; 1,730.
361	ARCO Columbia County 12-6 009-00198	NW¼ sec. 6 T. 5 N., R. 5 W. Columbia County	Application; 1,830

□

Landslides underestimated

Expert geologists point out that damages and losses caused by landslides are often overlooked or underestimated. In many cases, they are small, occur in isolated areas, and do not receive much public attention or news coverage. Yet, their cumulative effect makes them the most costly natural disasters in the nation.

Three recent examples illustrate the destructive potential of landslides: (1) On October 7, 1985, a landslide on a densely populated hillside at Mameyes, Puerto Rico, destroyed more than 100 homes and killed more than 125 people, after heavy rains from tropical storm Isabel had made the slope unstable. (2) During the eruption of Nevado del Ruiz in Colombia on November 13, 1985, hot volcanic materials melted ice and snow masses, thus causing mudflows that inundated communities and killed more than 20,000 people. (3) Persistent storms battered California and other western states in February 1986, creating numerous land- slides on water-soaked hillsides that caused millions of dollars in damage.

The following points were made by Darrell Herd, chief of the U.S. Geological Survey (USGS) land-slide program, and by USGS landslide experts Robert L. Schuster and Robert W. Fleming:

- While the examples above are not typical of the landslide damage sustained each year, the death toll from landslides in the United States averages about 20-25 deaths per year.
- Direct and indirect costs to public and private property run into the billions of dollars worldwide and average an estimated $1.5 billion per year in the U.S.
- Direct and indirect losses from landslides in the U.S. each year are about equal to the direct property losses from earthquakes in the U.S. over the past 20 years combined.
- In addition to killing people and livestock and damaging or destroying buildings and other facilities, slope failures are destructive to agricultural and forest lands and impair the quality of water in rivers and streams. Indirect costs of landslides include such things as loss of productivity of agricultural and forest lands, reduced real estate values, loss of productivity and wages in industries hit by landslides, and loss of property tax revenues. Such indirect costs may exceed the direct costs.
- The most expensive landslide in U.S. history occurred in 1983, blocking Spanish Fork Canyon at Thistle, Utah. The landslide dam formed a large lake, causing the town of Thistle to be flooded and blocking two major highways and a rail line through the canyon. Losses were estimated at $250 million.
- How landslide losses are often greater than is generally recognized is illustrated by the tremendous destruction in central Virginia in 1969 that is remembered as an effect of Hurricane Camille. In fact, most of the 150 people killed during the storm died in debris flows caused by the heavy rains.
- While most landslides still occur in unpopulated areas, a growing number hits populated areas as construction expands into landslide-prone hillside areas. Human activity disturbs large volumes of earth and rock in construction of highways, buildings, mines, dams, and other facilities and has become a major factor in an increase in landslides.
- In order to anticipate extensive landsliding such as occurred in California earlier this year, the USGS has set up a rain-gauge network that can alert to rainfall amounts that might trigger landslides. The USGS, then, gives information to the National Weather Service, which, in turn, can issue special landslide advisories to the public in conjunction with its weather reports.

— USGS news release

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VOLUME 48, NUMBER 7 **JULY 1986**

THIS MONTH:

ORIGIN OF THE WILLAMETTE METEORITE

and annual summary:

GEOTHERMAL EXPLORATION IN OREGON, 1985

OREGON GEOLOGY

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

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

COVER PHOTO

Willamette meteorite in front of the Johnson farm in the town of Willamette, a part of the southern outskirts of Portland. The meteorite at this point was being moved from the original finder's property toward the Willamette River for transportation to Portland and, ultimately, New York. Related article beginning on next page discusses a new hypothesis concerning the meteorite's origin. Photo courtesy Harold Johnson.

OIL AND GAS NEWS

Columbia County lease sale rescheduled

The lease sale originally scheduled for June 11 has been rescheduled for July 28. The delay was brought about by an early June discussion of the lease terms with industry representatives and representatives of taxing districts. Changes now being made include those regarding ownership of gas storage wells, commitment to drill offset wells, and the definition of the starting date of drilling.

The lease sale will be held in the Old Courthouse, First Street, St. Helens, Oregon, at 10 a.m. Additional information is available from the Board of Commissioners, phone (503) 397-4322.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft), use
362	ARCO Columbia County 21-11 009-00199	NW¼ sec. 11 T. 5 N., R. 3 W. Columbia County	Application; 11,500.
363	Oregon Natural Gas OM 44D-3 009-00200	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Application 3,400; Gas storage.
364	Oregon Natural Gas OM 12C-3 009-00201	NW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Application; 3,400; Gas storage.
365	Oregon Natural Gas OM 12D-10 009-00202	NW¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Application; 3,000; Gas storage.
366	Oregon Natural Gas OM 41A-10 009-00203	NE¼ sec. 10 T. 6 N., R. 5 W. Columbia County	Application; 3,100; Gas storage.
367	Oregon Natural Gas OM 14A-3 009-00204	SW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Application; 3,400; Gas storage. □

Circum-Pacific Council announces energy summit

The largest display of energy data on the Pacific ever assembled is planned for the fourth Circum-Pacific Energy and Mineral Resources Conference to be held August 17-22, 1986, in Singapore.

Under the auspices of the Circum-Pacific Council for Energy and Mineral Resources, which was founded in 1972 by Michel T. Halbouty and has been affiliated with the American Association of Petroleum Geologists since 1982, 120 speakers are expected to address an international audience, 60 percent of which will be from countries other than the United States. At least 50 different data displays covering over 100 regions and contributed by approximately 170 scientists from 30 nations are scheduled to be shown to earth scientists and representatives of government and industry.

According to Halbouty, the conference is considered an energy "summit" that will set the stage for future exploration in the Pacific region. Further information may be obtained from Anthony P. Hatch, Public Affairs Chairman, Circum-Pacific Council, c/o Times/Mirror, Times Mirror Square, Los Angeles, CA 90053, phone (213) 972-3727; and, during the conference, from the Circum-Pacific Conference Press Office, Westin Raffles City Convention Center, 2, Stamford Road, Singapore, phone 338-8585.

— *Circum-Pacific Council news release*

Origin of the Willamette meteorite: An alternate hypothesis

by Richard N. Pugh, Science Department, Cleveland High School, 3400 S.E. 26th Street, Portland, OR 97202; and John Eliot Allen, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207

INTRODUCTION

The Willamette meteorite was found in 1902 on the east side of the Tualatin Valley 2 mi northwest of West Linn, Oregon. It weighs 31,107 lbs, or slightly over 5½ tons. It is the largest meteorite ever found in the United States and the sixth largest ever found in the world (Lange, 1962). Did it really fall in Oregon?

HISTORY

Ellis Hughes found the meteorite in the fall of 1902 while he was cutting wood on land belonging to the Oregon Iron and Steel Company. In describing the find he said, "I sat down on the rock. It was about 1½ ft above the ground and very flat." Bill Dale came by and said, "Hughes, have you seen this rock before?" "Yes," I said, "I saw it yesterday. Then I picked up a large white stone and started to hammer on the rock. It rang like a bell." "Hughes," Dale said to me, "I'll bet it is a meteor" (Lange, 1962).

With the aid of his wife, his son, and a horse, Hughes was able to move the bell-shaped meteorite in a secretive manner the nearly three-quarters of a mile to his own property. This task took three months of sweat and toil and included the building of a road through the forest in order to transport the meteorite on a handmade, wooden-wheeled cart. Once Hughes got the meteorite on his land, he built a shed over it and charged sightseers 25¢ to view the space rock (Lange, 1958).

An attorney for the Oregon Iron and Steel Company was one of those who paid his quarter to see the meteorite. He also noted the road from the company's land. On November 27, 1903, the company sued Hughes, and after three court trials, the last in the Oregon Supreme Court, it was ruled that "Meteorites, though not imbedded in the earth, are real estate, and consequently belong to the owner of the land on which they are found" (Lange, 1962).

The meteorite was then transported to the Willamette River, where it was barged to Portland and exhibited at the 1905 Lewis and Clark Exposition. It was subsequently purchased by Mrs. William A. Dodge II of New York, who gave it to the American Museum of Natural History. When the Hayden Planetarium was added to the museum in 1936, it became the home of the Willamette meteorite.

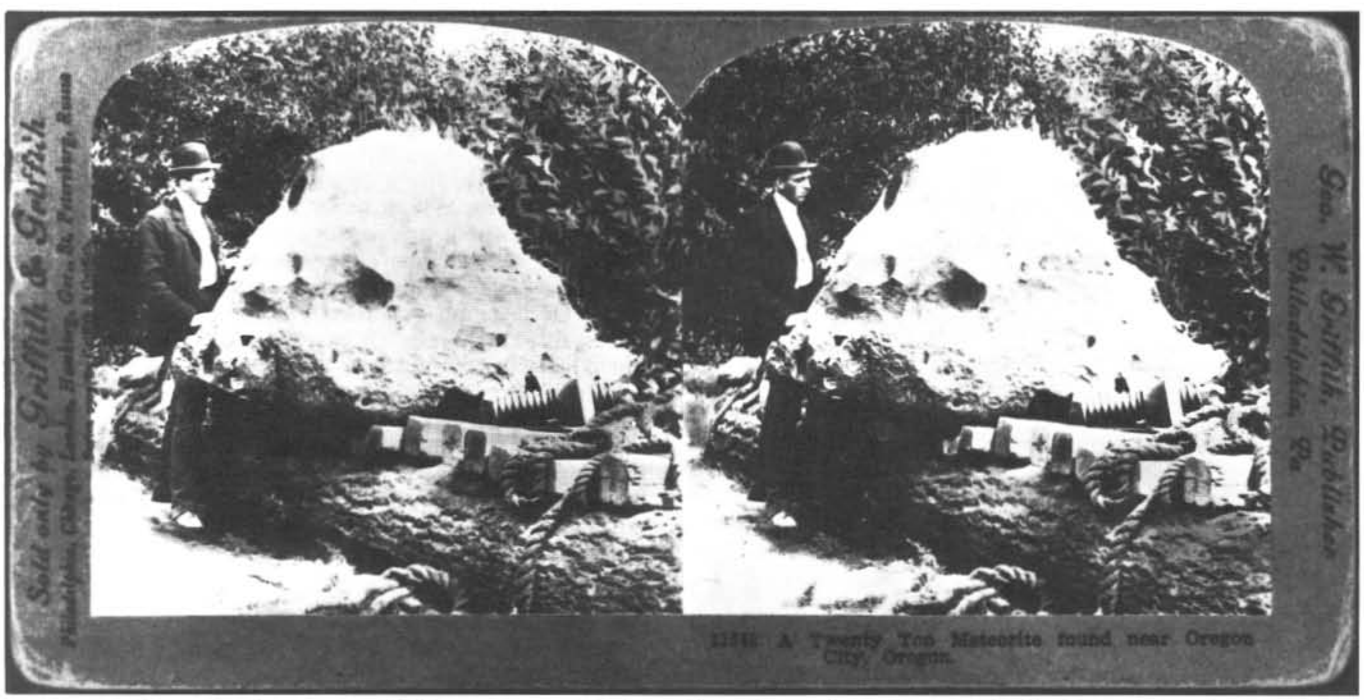
DESCRIPTION

The measurements (Ward, 1904) are: length, 10 ft, 3½ in.; breadth across the base, 7 ft; vertical height, 4 ft; circumference around the base, 25 ft, 4 in. The shape is that of the broad cone of an "oriented meteorite" (it is the largest one known). It is generally believed that this shape is the result of its orientation when it entered the atmosphere and the subsequent ablation as it came down point first through the air.

The meteorite is classified as a medium octahedrite, with a chemical composition of 91.5 percent iron, 7.62 percent nickel, and 0.45 percent cobalt, which places it in the chemical group IIIA. It went through two episodes of recrystallization and annealing before entering the earth's atmosphere (Buchwald, 1975).

The shallow pit from which the meteorite was removed still exists. It is lined with several inches of rust caused by the weathering. Several years ago, Russel A. Morley, research geologist of Salem, collected specimens and also soil samples for several feet around the crater. They gave positive tests for nickel, showing that the nickel leached from the meteorite had been deposited in the surrounding soil (Lange, 1965).

It has been calculated that at least 6 tons of the meteorite had rusted away during the last 13,000 years. This would mean that its weight when it first fell would have been in excess of 20 tons (Buchwald, 1975).



Stereopair photographs of Willamette meteorite in front of the Johnson farm. Photo supplied by Harry Czyzewski.

Willamette meteorite on wagon made by Ellis Hughes. Photo from Ward (1904).

Willamette meteorite in front of the Johnson farm. Photo supplied by Harry Czyzewski

The Willamette meteorite is unique for its great hollows, deep pits, basins, and holes, some of which pass entirely through the meteorite. "These excavations in our meteorite are clearly the result of the action of water " (Ward, 1904).

The number of solution holes and basins (some of them the size of small bathtubs) in the upper flat surface are the result of the acid action of decaying vegetable matter and the heavy Oregon rains. One of the components of the meteorite is triolite, or iron sulfide, which weathers to produce sulfuric acid and accelerates the corrosion. It is probable that some of the holes and basins once contained larger amounts of triolite than the rest of the meteorite.

ORIGIN

A lobe of the continental ice sheet, coming down the Purcell trench and up the Clark Fork River southeast of Lake Pend Oreille, Idaho, formed 2,500-ft-high ice dams that repeatedly impounded up to 500 cu mi of water in ice-age Lake Missoula.

Each time the water in the lake reached a height sufficient to float and undermine the ice in the dams, they shattered and broke up, releasing tremendous amounts of water that roared across eastern Washington and down the Columbia River. This occurred at least 40 times at intervals of about every 55 years for over 2,000 years.

These cataclysmic floods, which swept through the Oregon City area and on up the Willamette Valley as far south as Eugene between 15,000 and 12,800 years ago, reached an elevation of nearly 400 ft. In them, floating icebergs from the ice dams carried frozen within them thousands of blocks of rock and debris that had been carried down by the ice lobe from Canada.

Willamette meteorite showing bowl-shaped cavities. Photo from Ward (1904).

As each flood receded, some of the icebergs were stranded, and they melted and released their loads. More than 300 "erratic" boulders and rocks of granite, granodiorite, gneiss, and other rocks from Canada were found and mapped 50 years ago within the Willamette Valley by Ira Allison (1935) of Oregon State University.

The largest such erratic found in Oregon is the one on a spur at 302-ft elevation between Sheridan and McMinnville, in Oregon's smallest state park. It originally weighed 160 tons, nearly eight times as much as the original 21-ton weight of the Willamette meteorite.

The location of the Willamette meteorite, 2 mi from the mouth of the Tualatin River near the top of a spur at 380 ft elevation, is near the center of sec. 27, T. 2 S., R. 1. E. The location formerly cited in the literature is in error by nearly 5 mi; the accurate location is lat. 45° 22′ 6″ N., long. 122° 40′ 7″ W.

Since this is an ideal spot for one of the icebergs, coming up the Tualatin Valley in a side eddy from the main flood in the Willamette, to have been stranded and to have dropped its load, both the authors, for 20 years, have toyed with the hypothesis that the meteorite was rafted in, frozen in an iceberg.

The original weight of the meteorite was 21 tons. Simple calculations show that it could have been floated within an iceberg cube only 25 ft on a side.

Until a few months ago, this idea was just a hypothesis, a suggestion derived from circumstantial evidence. Last year, Pugh, with the help of Carole Lange, was able to relocate the site where the meteorite was found. In digging around near the almost-filled shallow hole from which it was taken, Pugh again found the abundant fragments of iron rust from the weathered surface of the meteorite (Allen, 1936), but he also found something much more important.

While walking around the area he found, 600 ft directly down the slope, a 12-inch boulder composed of granodiorite, which does not occur in bedrock within the Willamette Valley. Later, after clearing brush, poison oak, and blackberries from the hole, he found dozens of small erratic pebbles of granite within 3 ft of the depression. Remember that Ellis Hughes refers to picking up a "white rock" at the site which he used to pound on the meteorite.

Pugh suggests that, since a cone-shaped meteorite falls point down, the Willamette meteorite would have imbedded itself in

*(Continued on page 85, **Meteorite**)*

Geothermal exploration in Oregon, 1985

by Neil M. Woller, Gerald L. Black, and George R. Priest, Oregon Department of Geology and Mineral Industries

LEVEL OF GEOTHERMAL EXPLORATION

Introduction

Despite signs of improvement in the nation's financial conditions, the geothermal industry in general has been negatively influenced by falling petroleum prices and an overall power surplus in the Pacific Northwest. The results in Oregon have been a decline in the number of lease applications filed, the amount of acreage leased, and the level of exploration drilling.

Drilling activity

Figure 1 shows the number of geothermal wells drilled and geothermal drilling permits issued in Oregon. Table 1 lists new geothermal drilling permits issued in 1985. The apparent increase to 11 permits (as compared to six for 1984) is somewhat misleading, as eight of the 11 issued permits are actually renewals of expired permits. The permits in this group of renewals were filed by California Energy Corporation for sites along the east margin of Crater Lake National Park and Newberry volcano.

The remaining three permits listed in Table 1 were issued to GEO Operator Corporation. Two of their permit applications are for holes on the flanks of Newberry volcano and are part of the U.S. Department of Energy's industry-coupled drilling program. GEO Operator's N-1 hole, located on the south flank, has been drilled to 1,387 m and is discussed in a later section. The N-3 hole, located on the north flank, is scheduled for drilling in 1986. The third GEO Operator Corporation permit was issued for a hole in the Vale Known Geothermal Resource Area (KGRA).

Plans were also announced for the drilling of two other wells in the Cascades as part of the cost-sharing agreement between the U.S. Department of Energy (USDOE) and industry. Thermal Power will drill a 1,524-m-deep well in the Olallie Butte-Sisi Butte area (northwest of Mount Jefferson) in the summer of 1986. This site was permitted in early 1986 and therefore is not listed in Table 1. John Hook and Associates have also been accepted as participants in the USDOE program and are expected to drill in the Blue Lake area of Santiam Pass in the fall of 1986, pending further negotiations with USDOE

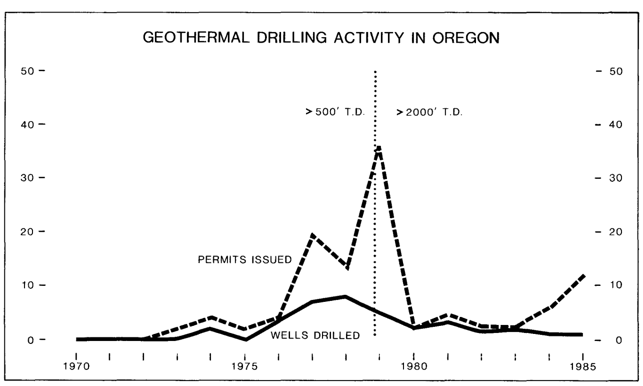


Figure 1. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 2,000 ft. Note that eight of the 11 new permits are for previously permitted sites (under different permit numbers).

Table 1. *Permits for geothermal drilling in 1985*

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
113	California Energy MZI-3 035-90011	SW¼, sec. 12 T. 30 S., R. 6 E. Klamath County	Application; 4,000.*
114	California Energy MZI-9 035-90012	NW¼, sec. 11 T. 31 S., R. 7½ E. Klamath County	Application; 4,000.*
115	California Energy MZI-11 035-90013	SW¼, sec. 15 T. 31 S., R. 7½ E. Klamath County	Application; 4,000.*
116	California Energy MZI-11A 035-90014	SW¼, sec. 10 T. 31 S., R. 7½ E. Klamath County	Application; 4,000.*
117	California Energy MZII-1 035-90015	SE¼, sec. 13 T. 32 S., R. 6 E. Klamath County	Application; 4,000.*
118	GEO Operator N-1 017-90013	NW¼, sec. 25 T. 22 S., R. 12 E. Deschutes County	Suspended; 4,550.
119	GEO Operator N-3 017-90014	NW¼, sec. 24 T. 20 S., R. 12 E. Deschutes County	Application pending; 4,000.
120	California Energy CE-NB-1 017-90015	NW¼, sec. 16 T. 22 S., R. 12 E. Deschutes County	Application; 4,000.*
121	California Energy CE-NB-2 017-90016	SE¼, sec. 18 T. 22 S., R. 13 E. Deschutes County	Application; 4,000.*
122	California Energy CE-NB-3 017-90017	NW¼, sec. 16 T. 22 S., R. 13 E. Deschutes County	Application; 4,000.*
123	GEO Operator VF #1 045-90006	NW¼, sec. 11 T. 19 S., R. 45 E. Malheur County	Application; 10,000.

* *New application on expired permit*

(John Hook, personal communication, 1986).

Figure 2 shows that virtually no prospect holes (shallower than 152 m in depth) were drilled in 1985. This reflects both the general decline of geothermal exploration in Oregon and also the fact that areas that are undergoing active geothermal exploration in the Cascade Range must be drilled to depths of 600 to 1,500 m in order to yield meaningful temperature-gradient and heat-flow data.

Leasing

Figure 3 shows the change of pattern of active geothermal leases of federal lands in Oregon from 1974 through 1985. Both it and Table 2 indicate that the total number of federal leases declined by 15 percent in 1985. The greatest decrease (in acres) is in noncompetitive leases on lands administered by the U.S. Forest Service (USFS). This decrease in leased Forest Service lands is partially a result of Sunedco Development Corporation's abandonment of its Cascade lease positions despite the generally favorable results of its geothermal exploration program. The Sunedco 58-28 well, drilled in the Breitenbush area in 1981, encountered a hot aquifer (115° C from a thermistor probe; 136° C from a maximum-reading thermometer) at 752 m. Geologic and temperature data in preparation by Oregon Department of Geology and Mineral Industries (DOGAMI) personnel and by Albert Waibel of Columbia

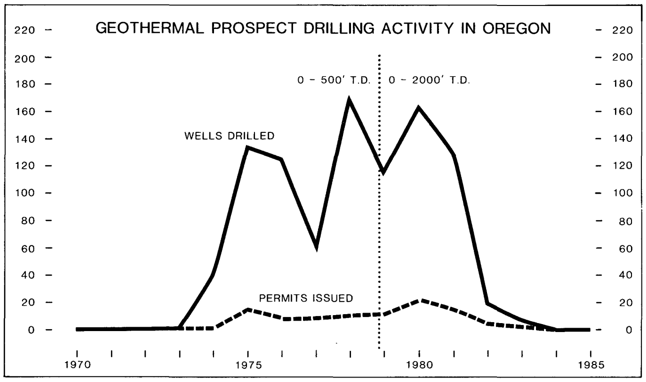


Figure 2. Geothermal prospect-well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth less than 2,000 ft.

Geoscience indicate that the aquifer dips to the east and consequently may be encountered at greater depths and higher temperatures in poten-tial drill sites to the east. Well 58-28 was drilled to a total depth of 2,457 m. Bottom-hole temperatures from maximum-reading thermometers suggest that the average gradient for the hole is very close to the estimated regional gradient for the Cascade heat-flow anomaly (60° C/km, Blackwell and others, 1978, 1982).

Table 2. *Geothermal leases in Oregon, 1985*

Types of leases	Numbers	Acres	
Federal active leases:			
Noncompetitive, BLM	41	59,027	
Noncompetitive, USFS	242	461,426	
KGRA, BLM	9	24,062	
KGRA, USFS	2	1,400	
Changes during 1985:			
Total 1/1/85	343	641,499	
Noncompetitive, BLM	-6	-14,533	(-20%)
Noncompetitive, USFS	-32	-60,739	(-12%)
KGRA, BLM	-6	-11,920	(-33%)
KGRA, USFS	-5	-8,391	(-86%)
Subtotal	-49	-95,583	(-15%)
Total 12/31/85	294	545,916	
Federal leases relinquished:			
Noncompetitive, BLM	219	346,220	
Noncompetitive, USFS	68	131,788	
Competitive, BLM	49	89,185	
Competitive, USFS	7	11,565	
Federal leases pending:			
Noncompetitive, BLM	0	0	
Noncompetitive, USFS	213	No data	
State leases:			
Total active in 1985	No data	No data	
Total applications pending (1985)	No data	No data	
Private leases:			
Total active in 1985	No data	No data	

Results of new drilling at Newberry volcano

GEO Operator drilled a hole (N-1) on the south flank of Newberry volcano (Figure 4) to a total depth of 1,387 m. The cost of drilling the upper 1,219 m was shared by USDOE, while the lower 168 m of the hole was funded solely by GEO Operator Corporation. The information collected from the surface to 1,219 m is therefore available to the public and is partially presented here. The information collected from the last 168 m is the property of GEO Operator. Core was collected from 148 to 1,355 m.

The temperature profile presented in Figure 5 is from data collected one week after completion of the hole and is therefore not yet stable. The mud circulated during drilling has the effect of warming the upper portion of the hole and cooling the lower portion. Mud circulation is therefore a moderating influence on the thermal gradient. It is expected that the stable temperature profile (to be collected in the summer of 1986) will have a somewhat higher bottom-hole temperature and gradient than presented here.

The profile for N-1 (Figure 5) is essentially isothermal to a depth of 800 m. This isothermal zone is characterized by andesites, basalts, and basaltic andesites. The drill log reports circulation losses for portions of this interval, and it is probable that circulation of meteoric water and air has "washed out" the normal temperature gradient in this zone. From 800 m to 1,000 m, the temperature slowly increases, and the gradient for this zone increases from 26° C/km in the upper part to 69.5° C/km in the lower part.

At 1,000 m, the gradient is very high, marked by a rapid increase in temperature from 17° to 45° C. From 1,040 m to approximately 1,160 m, the gradient is 129.5° C/km. From 1,180 m to 1,219 m, the average gradient decreases slightly to 90.7° C/km. The gradient from 1,207 m to 1,219 m is 86° C/km. Therefore it appears the gradient is in transition and decreasing in the lower part of the well.

Blackwell and Steele (1983) suggested that the background gradients and heat flow for Newberry volcano are 40°-65° C/km and 1.9-2.5 heat-flow units (HFU), respectively. Although the gradients in the lower part of the N-1 well are decreasing, all are above the regional background gradient expected for this area. Once heat-flow values are determined from conductivity measurements and stabilized temperature profiles, a more definitive interpretation will be possible.

KGRA SALES

No KGRA lands were offered for bid in 1985.

DOGAMI RESEARCH

Total-field aeromagnetic anomaly maps for the northern Cascade Range were published by DOGAMI in 1985 as GMS-40 (Couch and others, 1985). The maps were authored by R.W. Couch, M. Gemperle, and R. Peterson of the Oregon State University Geophysics Group. Publication of these maps completes aeromagnetic coverage of the Oregon Cascade Range.

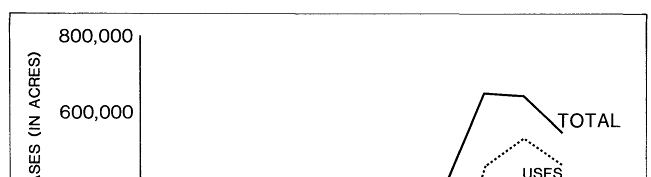


Figure 3. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December 1985. Note changes in pattern over time.

DOGAMI geothermal staff completed mapping in the Breitenbush River and Coffin Butte areas of the central Oregon Cascade Range. Two maps, each encompassing the area of a standard 15-minute quadrangle, are scheduled for publication in late 1986. Field work for the 1986 field season will consist primarily of mapping in the McKenzie Bridge quadrangle in the central Oregon Cascades. This map is scheduled for release in 1987. Some additional mapping will be completed in the vicinity of the Thermal Power drillhole, which is scheduled to be drilled this summer northwest of Olallie Butte.

In addition to the two maps mentioned above, several other geothermal-related publications are scheduled for release by DOGAMI in 1986. Work has progressed on the plan for deep drilling in the central Cascades. A nontechnical summary, *A Program for Scientific Drilling in the Cascades, Northern California, Oregon, and Washington,* was published in March 1986. A more detailed technical discussion of the plan for deep drilling will be published as a DOGAMI open-file report later in 1986.

Additional publications include a recently released openfile report (O-86-2) that summarizes all heat-flow data generated by DOGAMI since 1982 and two upcoming publications—a publication containing a geologic map of the northwest quarter of the Broken Top quadrangle by E.M. Taylor of Oregon State University and an *Oregon Geology* article on hydrothermal alteration in Sandia Laboratories Newberry volcano drill hole RDO-1 by T.E.C. Keith, U.S. Geological Survey (USGS); M.W. Gannett, Columbia Geoscience and now Oregon Department of Water Resources; J.C. Eichelberger, Sandia National Laboratories; and A.F. Waibel, Columbia Geoscience.

U.S. GEOLOGICAL SURVEY ACTIVITIES

The USGS continued to work on Cascade projects during 1985. The USGS program in Oregon has consisted chiefly of surface geological and geophysical surveys of young Cascade volcanoes.

Preliminary results from the Newberry seismic experiment in 1984 were presented to the Geothermal Resources Council in August 1985 (Stauber and others, 1985). The high-resolution seismic imaging experiment discovered a ring of high-*P*-velocity material in the upper 2 km around the caldera ring-fault system. A low-velocity zone was found in the center of the caldera. Stauber and others (1985) concluded that the "low-velocity zone in the center of the caldera is inferred to extend somewhat deeper than the high-velocity ring and is a possible source region for the high-silica rhyolitic magmas which have erupted in the caldera several times in the last 6,000 years." This statement stops short of saying that the low-velocity zone is in fact a silicic magma chamber with substantial percentages of molten rock. Further experiments, perhaps concentrating on seismic shear wave analysis, may help to determine if there is a molten magma body under the caldera (Stauber, personal communication, 1986). In view of the high expense of the shear wave experiments (Stauber, personal communication, 1986) and the shallow depth of the anomaly, drilling into the low-velocity zone may be the best means of determining if it is molten or not.

In May 1985, the USGS sponsored a workshop at its Menlo Park, California, headquarters on the geothermal resources of the Cascades. Numerous Cascade researchers, chiefly from the USGS, gave papers summarizing their research in Oregon, California, and Washington. The proceedings were published as USGS Open-File Report 85-521 (Guffanti and Muffler, 1985). Many of the papers presented summaries of old data. New geophysical models of electrical data from Mount Hood and presentation of a new geothermometer were highlights of the meeting. The electrical data at Mount Hood showed a number of conductive zones that could be geothermal reservoirs under the volcano (Goldstein, 1985). Robert Mariner (1985) presented a new geothermometer based on anhydrite saturation. Anhydrite-estimated reservoir temperatures for Austin Hot Springs (186° C), Breitenbush Hot Springs (174° C), Bigelow Hot Springs (155° C), Belknap Hot Springs (152° C), Rider Creek Hot Springs (135° C), Wall Creek Hot Springs (160° C), McCredie Hot Springs (130° C), and Kitson Hot Springs (134° C) are comparable to values of the sulfate-water geothermometer but much higher than estimates by most other standard geothermometers. Mariner (1985) also determined that the headwaters of the Metolius River and the Spring River contribute anomalously high amounts of chloride to streams flowing out of the east-central High Cascades. Similar high chloride contents were measured in Blue Lake, a young explosion crater near Santiam Pass on the eastern slope of the High Cascades (Johnson and others, 1985). This high chloride content may be indicative of geothermal resources at depth.

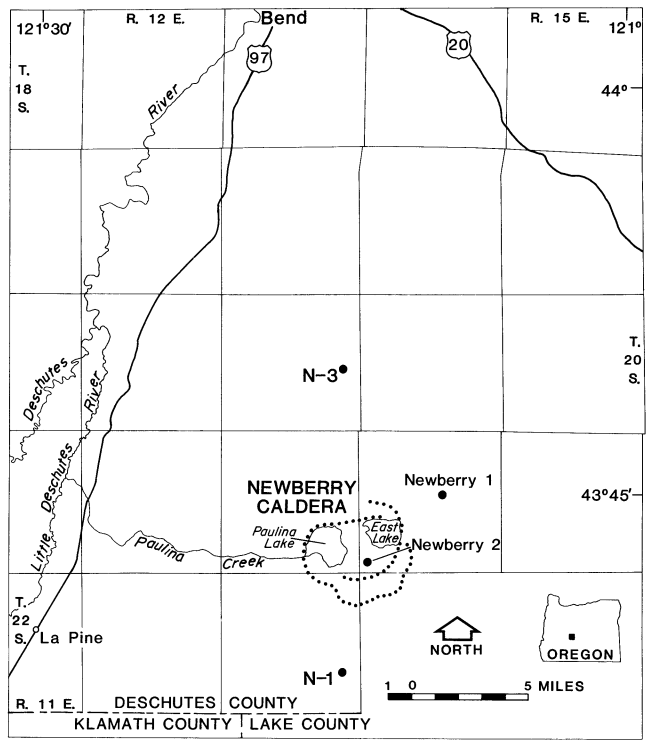


Figure 4. Location of GEO Operator Corporation wells on the flanks of Newberry volcano.

The Water Resources Division of the USGS started work on the hydrology of the central Oregon Cascades in 1985. The project is continuing in 1986 and includes an examination of surface waters from the Clackamas River south through the McKenzie River drainage. Samples are being taken for complete chemical and isotopic analysis. A complete well inventory and the acquisition of additional heat-flow data are also part of the study (Steve Ingebritsen, personal communication, 1986).

Other projects for 1986 include the publication of a paper on the flow test at the Newberry 2 drill hole. Authors are S.E. Ingebritsen, W.W. Carothers, R.H. Mariner, J.S. Gudmundsson, and E.A. Sammel. Sammel is also back from retirement working under contract on hydrologic modeling of Newberry volcano (Steve Ingebritsen, personal communication, 1986).

ACTIONS OF REGULATORY AGENCIES CONCERNING GEOTHERMAL EXPLORATION

The Oregon Land Use Board of Appeals ruled against proposed development of a patented claim in the interior of Newberry caldera. The affected claim, involving 157 acres in the central pumice cone, is owned by La Pine Pumice Company. The claim is totally surrounded by the resort area of Newberry caldera, which comprises two lakes, numerous campsites, and horse and hiking trails. The area is administered by the Fort Rock Ranger District of the Deschutes National Forest. The entire caldera is banned from geothermal development by the draft Deschutes National Forest Plan. The proposed development was valued at $15 million.

The decision was appealed and upheld by the Oregon Court of Appeals. In April, the Oregon Supreme Court denied a petition for review of the lower court decision, apparently killing any prospect for geothermal development inside Newberry caldera in the near future.

The U.S. Bureau of Land Management (BLM) has granted Geothermal Resources International, Inc. (GRI), a unitized claim on geothermal resources in the area surrounding Newberry caldera. The geothermal resource unit includes 240,000 acres, of which GRI has the geothermal rights on about 170,000 acres.

An appeal filed by the Sierra Club has led to the suspension of open leasing on 541,000 acres in the Bend and Crescent Ranger Districts of the Deschutes National Forest. The areas involved surround the Cascade Lakes Highway and proposed research natural areas and wetlands. The appeal suspended 19 existing leases. The USFS originally completed environmental impact statements (EIS) for the involved areas and decided to open the lands to geothermal leasing. The BLM, which handles geothermal leasing for the USFS, was satisfied with the USFS assessment and approved leasing. The Sierra Club contended, however, that BLM was required to complete its own environmental assessment before issuing leases. The Interior Board of Land Appeals supported the position of the Sierra Club. BLM must either complete an environmental assessment before reissuing the leases or reissue the leases with a no-surface occupancy proviso until the EIS is completed. At this time, the leases have not been reissued.

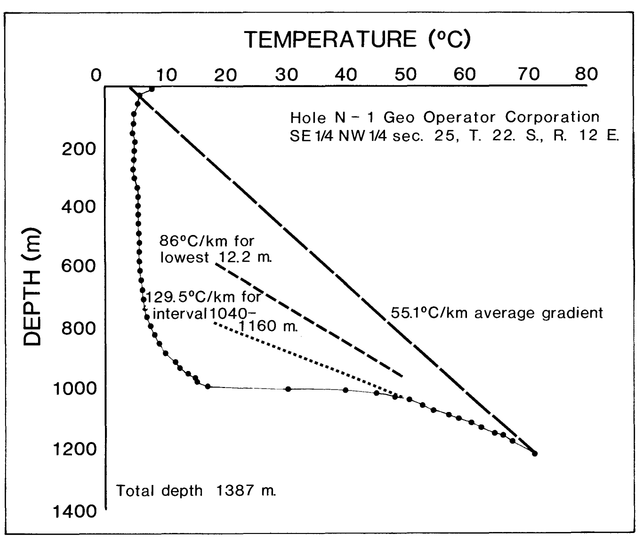


Figure 5. Temperature-depth profile of the upper 1,219 m of GEO Operator Corporation hole N-1, located on the south flank of Newberry volcano.

LOW-TEMPERATURE UTILIZATION

Klamath Falls

A geothermal resource management act was passed by the City of Klamath Falls in an effort to effectively develop and manage the low-temperature geothermal resource. Geothermal space heating is currently used in Klamath Falls to heat many public municipal buildings, Oregon Institute of Technology (OIT) campus buildings, and many private residences. The act (1) requires permitting of all new geothermal wells, (2) implements a free, voluntary registration of all privately owned geothermal wells, with the data to be stored in the recently formed Geothermal Data Center, and (3) requires discontinuance of surface discharge of geothermal waters within five years.

Consultants hired by the City of Klamath Falls to study recent drops in ground-water levels and to determine the feasibility of expanding the geothermal space heating base submitted their findings in late 1985. They found (1) the City heating system, which supplies heat to nine municipal buildings, had only minor impact on the geothermal aquifer, and continued usage of the system would not have much effect on the aquifer; (2) the decline in the aquifer was due to surficial discharge of thermal waters and/or increased demand on the aquifer in recent cold winters; (3) the considerable horizontal and vertical permeability in the geothermal system minimized the need to reinject water into specific zones of the system; and (4) surficial discharge could feasibly be used to expand district heating in the College Industrial Park and Mills addition, where 150 to 200 more homes could be added to the system. They also found that the city's two production wells could bear substantially increased loads.

The City of Klamath Falls has just started construction of a system to heat buildings on E. Main Street. The basic system will consist of a collection main that will supply heat to a secondary heat exchanger. A secondary supply loop will actually heat the buildings. Water for the collection system will be obtained from wells presently discharging into the storm sewer system. There are approximately 100 potential wells available to supply the system. Waste water from the collection main will be reinjected into the museum well, which is the reinjection well for the main Klamath Falls downtown heating system.

The U.S. Department of Housing and Urban Development (HUD) made funds available to private residences to tie into the existing geothermal system. The funds were originally in the form of low-interest loans, but the program eventually evolved into outright grants to homeowners who wished to take part in the program when the public response was very sluggish. When it became clear that there was still no significant public response, the City of Klamath Falls was forced to return $100,000 of the original $125,000 grant to HUD in early 1986.

Vale

Oregon Trail Mushrooms is producing mushrooms with geothermal heating at Vale. 110° C water is used to develop a compost which will support a strain of bacteria used by the mushrooms. The raw materials in the compost are straw, poultry manure, gypsum, and water, and the compost matures in four to five weeks. The plant is capable of producing 3.5 million pounds of mushrooms per year.

OREGON INSTITUTE OF TECHNOLOGY

The Oregon Institute of Technology (OIT) in 1985 continued with its technical assistance program which has been funded since the early 1970's by grants from USDOE. The program publishes a quarterly bulletin, provides speakers and tours on the direct use of geothermal energy, and provides up to 64 hours of feasibility analysis for small-scale geothermal developers. Funding for the program ran out on June 30, 1986, but it is hoped that funding for the program will be renewed (Paul Lienau, personal communication, 1986).

In 1985, OIT also continued its program of feasibility studies for direct-use projects in the State of California. The program is two years old and will continue in 1986.

Other projects planned for this year include a feasibility study of heating the Industrial Park with waste water from the OIT campus and from the Merle West Medical Center and an evaluation of the binary generator at the Wabuska, Nevada, geothermal site.

At the present time, the OIT campus discharges 400-600 gallons per minute (gpm), and the Merle West Medical Center discharges an average of 150 gpm (300 gpm peak) of 140°-150° F waste water into the storm sewer system. The OIT study will determine if three existing wells in the industrial park are suitable as injection wells. These wells, ranging in depth from 400 to 1,500 ft, were originally drilled as geothermal production wells but were cold. The ultimate plan is to use waste water to heat buildings in the industrial park and then to discard the waste water in injection wells (Paul Lienau, personal communication, 1986).

The evaluation of the binary ORMAT generator at the Wabuska, Nevada, site is a joint project in cooperation with Engineering Power Research Institute, ORMAT Systems, Sierra Pacific, and Tads Enterprises. Funding is provided by a grant from the Oregon Department of Energy (ODOE).

OREGON DEPARTMENT OF ENERGY ACTIVITIES

In 1985, ODOE supported some OIT activities, subcontracted a number of studies to OIT, and responded to inquiries on geothermal energy and development from the public. Other ODOE functions include reviews of applications for state tax credits for geothermal heating development and technical support for the Northwest Power Planning Council. These activities are expected to continue in 1986.

ODOE, in cooperation with the Washington State Energy Office (WSEO), recently completed a study for the Bonneville Power Administration (BPA). The purpose of the study was to verify economic assumptions identified in the BPA four-state study. The primary focus was on ownership and financing relationships. The report has been submitted to BPA (Alex Sifford, personal communication, 1986).

In the fall of 1986, ODOE will publish a study of the district heating potential in the state. The study will include all potential heating sources (Alex Sifford, personal communications, 1986).

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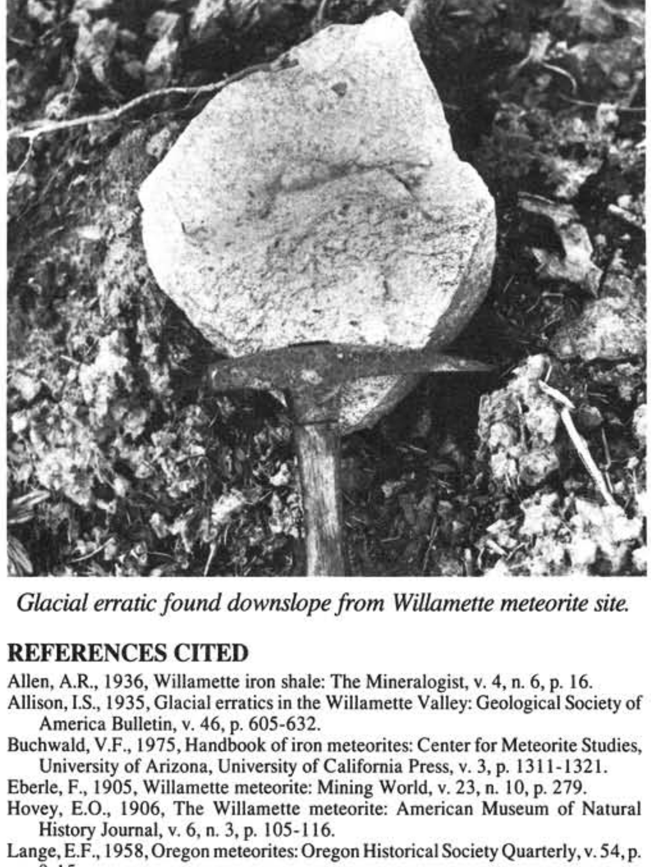
(Meteorite, continued from page 80)

the Cordilleran ice sheet in Canada in this position. During the flood, it would have acted as ballast within the iceberg, keeping the same position as it floated down the Columbia in the flood. When the iceberg stranded and melted, the meteorite would gently sink into the soil and remain in an oriented position with the flat side up.

There now appears to be reasonable doubt that the Willamette meteorite fell in Oregon. Instead, it could have come to Oregon from Canada via the ice sheet, making the final long journey from northern Idaho frozen in an iceberg.



Glacial erratic found downslope from Willamette meteorite site.

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Wermiel joins DOGAMI staff as petroleum geologist

Dan E. Wermiel has joined the staff of the Oregon Department of Geology and Mineral Industries (DOGAMI) as petroleum geologist. He earned a Bachelor of Science degree from the University of Miami, Florida, and a Master of Science degree from Arizona State University, Tempe, Arizona. Wermiel was employed with Barrett Resources in Denver, Colorado, as Vice-President of Geology.

Dan E. Wermiel

During his career, Wermiel has directed exploratory and development drilling programs, done surface and subsurface geology and petrophysical analysis of well logs, and prepared and reviewed drilling permits and programs.

His responsibility with DOGAMI will be the evaluation of proposed drilling programs, interpretation and application of Oregon rules and statutes, and field inspections of drilling operations. □

DOGAMI geologist co-authors USGS map

Len Ramp, Resident Geologist in the Grants Pass field office of the Oregon Department of Geology and Mineral Industries (DOGAMI), and Barry Moring, geologist with the U.S. Geological Survey (USGS), have collaborated on the recent publication of USGS Miscellaneous Field Studies Map MF-1735, *Reconnaissance Geologic Map of the Marial Quadrangle, Southwestern Oregon* (1986).

The map covers the geologically most interesting section of the Wild and Scenic Rogue River area and helps explain some of the more hazardous riffles such as Blossom Bar. The Marial quadrangle, situated on the border between northeast Curry County and northwest Josephine County, represents a previously unmapped area covering much of the Shasta Costa Creek drainage and a portion of the Mule Creek, Indigo Creek, and Silver Creek drainages.

The black-and-white map at a scale of 1:62,500 describes 21 rock units, most of them of Cretaceous and Jurassic age, as well as the geologic structure of the area. It outlines areas of sheeted diabasic dikes exposed along the Rogue River, Mule Creek, and Shasta Costa Creek that were described by Len Ramp and Floyd Gray in a 1980 article in *Oregon Geology* (v. 42, no. 7, p. 119-124).

The map is available for purchase from usual USGS outlets or from DOGAMI's Portland office. The price is $1.50. □

Coos Bay club displays minerals in Salem

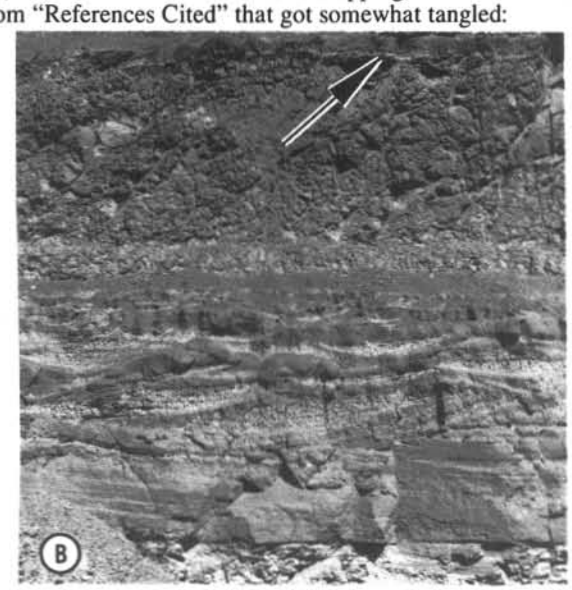
On June 7th, the Far West Lapidary and Gem Society of Coos Bay installed a new exhibit in the display case of the Oregon Council of Rock and Mineral Clubs at the State Capitol Building in Salem. Fifteen Oregon counties provided more than 90 separate items in 32 groupings for this display, which was arranged by Bert Sanne and Jeanne Larson of the Coos Bay club, assisted by George Larson, Cecelia Haines, and Lyle Riggs, who is the Council's agent for the display case.

Featured in the center of the exhibit is a hanging lamp made with several kinds of obsidian from Harney County. The arrangements include plume, tube, and snake skin agate; jade; Biggs jasper; thundereggs; serpentine; sagenite; carnelian; rhodonite; vistaite; fossils; petrified wood; limb casts; opal fashioned into bracelets; and faceted sunstones. Newly installed fluorescent lights have added to the beauty of the exhibit.

The current display will remain at the Capitol until early September, when the Eugene Mineral Club will present its display. Capitol Building hours are 8 a.m. to 5 p.m. on weekdays, 9 a.m. to 4 p.m. on Saturdays, and noon to 4 p.m. on Sundays. □

Correction

Two errors marred the printing of last month's article on the Simtustus Formation (*Oregon Geology*, v. 48, no. 6, p. 63-72). In order to correct them, we are reprinting here photo B from page 67, which suffered from excessive cropping, and three references from "References Cited" that got somewhat tangled:



Lower Simtustus Formation at Pelton Dam. Arrow points to air-fall tuff within tuffaceous mudstone.

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Separate price lists for open-file reports, geothermal energy studies, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request.

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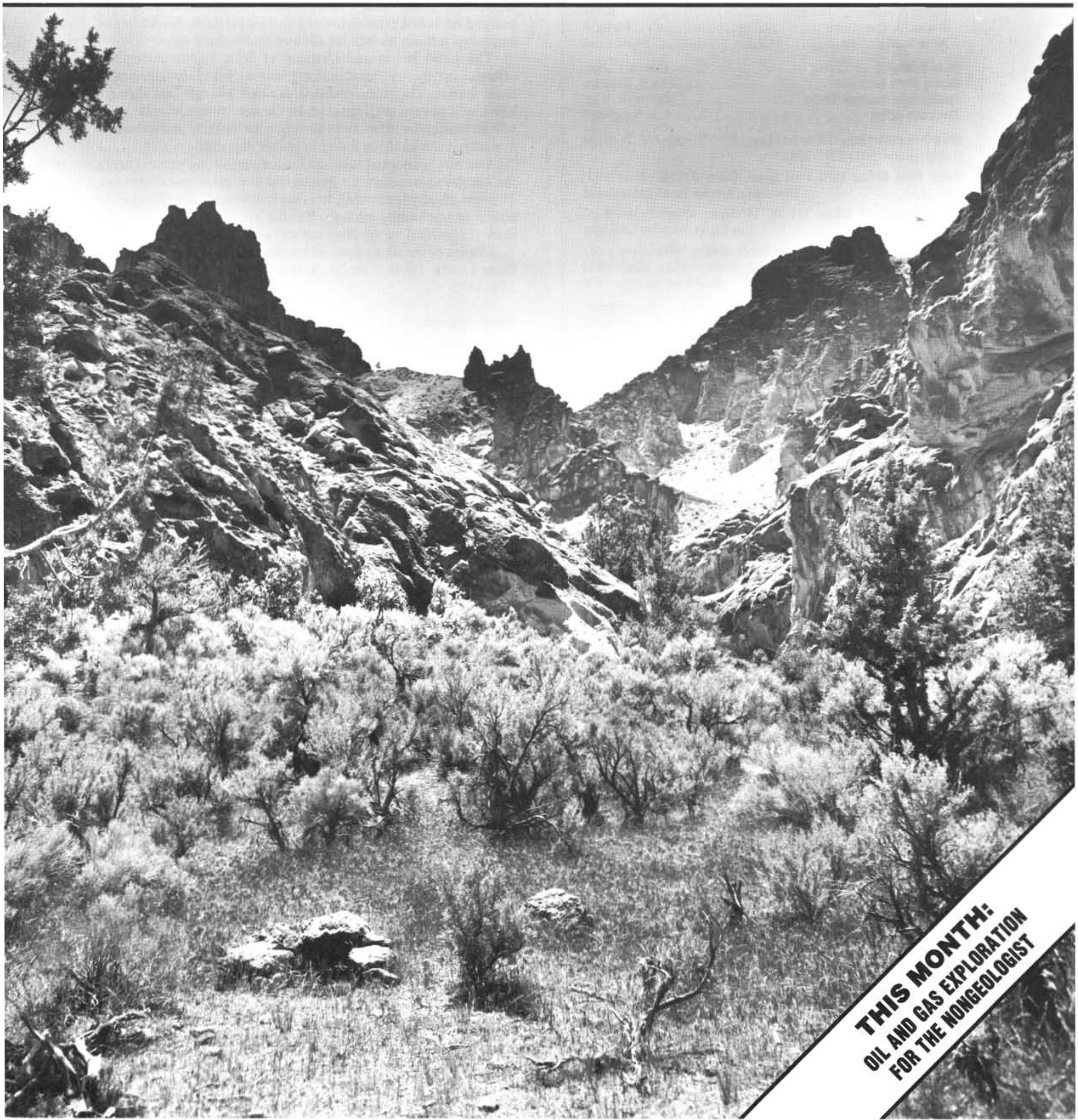

THIS MONTH:
OIL AND GAS EXPLORATION FOR THE NONGEOLOGIST

OREGON GEOLOGY
(ISSN 0164-3304)

VOLUME 48, NUMBER 8 AUGUST 1986

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Information for contributors

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

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

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

COVER PHOTO

Southeast Oregon country typical of the area covered by a study of geochemical data that was recently released by the U.S. Bureau of Land Management. See announcement and discussion on page 98. Photo courtesy Oregon State Highway Division.

OIL AND GAS NEWS

State Land Board adopts offshore rules

On June 27, the State Land Board, consisting of the Governor, Secretary of State, and State Treasurer, adopted new Oregon Administrative Rules governing offshore geological, geophysical, and seismic surveys in State waters. The rules, which had been in preparation for a year, will apply to oil, gas, and sulfur exploration under State-owned waters. This includes tidal submerged lands and extends to the 3-mi line offshore. No drilling or explosive techniques will be allowed under these rules.

The Land Board and Division of State Lands anticipates offshore surveys by the oil industry leading to eventual leasing in State waters. The rules, codified as OAR 141-10-201 through -290, will govern such surveys. In the near future, similar rules will be written for offshore exploration for metallic and industrial minerals, such as those found in placer deposits.

The newly adopted rules set forth a permitting process and a fee and bond structure for geological and geophysical surveys. The opportunity for a public hearing is provided, as well as public notice of impending surveys. Results are to be reported to the State if specified by the Division and are treated as confidential.

Copies of the new rules can be obtained from the Division of State Lands, 1600 State St., Salem, OR 97310, phone (503) 378-3805.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft), use
368	ARCO CFI 41-4 009-00205	NE¼ sec. 4 T. 5 N., R. 4 W. Columbia County	Application; 2,400.
369	ARCO CFI 31-22 009-00206	NE¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Application; 2,400.
370	ARCO CFI 12-5 009-00207	NW¼ sec. 5 T. 5 N., R. 4 W. Columbia County	Application; 4,850.
371	ARCO CFI 12-12 009-00208	NW¼ sec. 12 T. 5 N., R. 5 W. Columbia County	Application; 2,400.
372	Oregon Natural Gas Dev. OM 32a-11 009-00209	NE¼ sec. 11 T. 6 N., R. 5 W. Columbia County	Application; 3,000; gas storage.
373	Oregon Natural Gas Dev. IW 34d-3 009-00210	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Application; 2,800; gas storage.
374	Oregon Natural Gas Dev. OM 43c-3 009-00211	SE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Application; 3,000; gas storage.

□

Correction

In last month's issue (v. 48, no. 7, July 1986), two errors occurred in the article on the Willamette meteorite: On p. 79, the weight of the meteorite is, of course, "31,107 lbs. or slightly over 15½ tons." And on p. 80, the name of the mineral that is one of the meteorite's components is, of course, "troilite."

Oil and gas exploration (for the nongeologist)

by Wesley G. Bruer, Consulting Geologist, St. Helens, Oregon 97051

This is the first in a series of articles on the oil and gas industry that have been written for *Oregon Geology* by people who work in various occupations within the industry itself. This particular article tells in nontechnical terms how oil and gas form and why they are found where they are. Future articles, which will appear at irregular intervals in upcoming issues of *Oregon Geology*, will discuss such topics as leasing and geophysical exploration. — *Editor*

INTRODUCTION

If you have ever passed by an oil drilling rig, a well producing oil or natural gas, or an abandoned drill site and wondered how it was decided to drill in that particular place, then this article may be for you.

Exploratory wells are drilled with the hope of finding an underground accumulation of oil or natural gas, collectively known as hydrocarbons, big enough to be worth developing commercially. Before such an accumulation, or pool, can form, certain conditions must be met in the area. First, there must be or have been source rocks, that is, rocks containing enough organic material to have served as a source for the hydrocarbons. Second, there must be rocks, called reservoir rocks, that are porous enough to have space available to be occupied by the hydrocarbons and permeable enough to allow fluids to move in and out of the rocks. Third, there must be a layer of cap rock that is not readily permeable to oil or gas and that is in a position to hold the hydrocarbons in the reservoir. Fourth, there must be a trap, that is, the rock units in and near the pool must be shaped in three dimensions in such a way as to cause the hydrocarbons to migrate into, accumulate in, and stay trapped in the pool. And fifth, all of these necessary rocks and relationships must have come into being and have been properly shaped in the right sequence over sufficient geologic time. Together, we will consider each of these factors in more detail below. Since all of them must exist at the same place and time, you may already have an inkling as to why oil and gas fields occur under such a tiny fraction of the earth's surface.

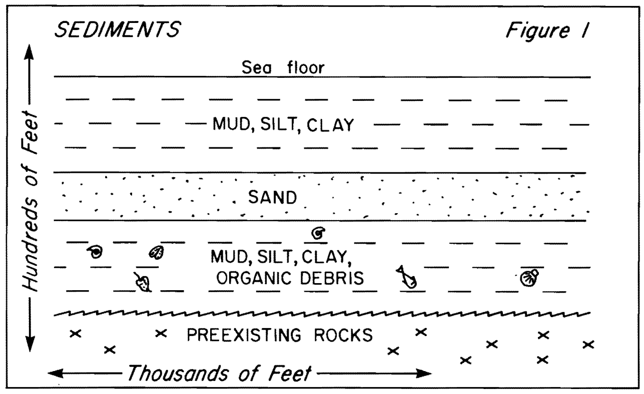
SOURCE ROCKS

In addition to water, streams carry a fluctuating load of sediment to the sea or to lakes. For our purposes, the term "sea" will also include "large lake." Rock and mineral particles make up most of this load. Depending on the climate, the volume, velocity, and gradient of the stream, and the nature of the countryside drained by the stream, these particles can range in size from boulders down through gravel, sand, silt, and clay.

Organic debris is also part of the sediment load. This may include everything from uprooted trees and large animal remains down through sticks, leaves, dead fish, insects, peat dust, algae, pollen, spores, and other microscopic plant and animal remains.

On reaching the sea, stream currents dissipate, their velocity decreases, and the sediment load tends to settle out. Sometimes this happens in the lower reaches of the stream itself. Other agents, such as ice and wind, can also carry material to the sea. Sediments derived from land are joined in the sea itself by organic remains, especially of plankton, and by rock and mineral particles originating within or at the margins of the sea. Waves, tides, and currents may continue to transport all or part of the sediments, but eventually they are deposited on the bottom.

Swift currents or vigorous wave action can carry heavy particles. Where a current begins to slow, it drops the heaviest part of its sediment load, such as boulders and cobbles. As it continues to slow, it will drop the pebbles, then the sand-size grains, then silt, and finally clay particles. Thus, sediments tend to get segregated by size as they are deposited. Organic material, being of lower density than most inorganic particles, commonly ends up with the fine-grained sediments, that is, silt and clay (Figure 1).



The organic part of the sediments that is not destroyed by living organisms or by chemical reaction (mostly oxidation), during transport is, of course, deposited along with the inorganic particles. With continued deposition, the organic material is eventually buried deeply enough to preserve it from living organisms, especially bacteria. Preservation is usually best in the finer grained sediments.

Bacterial destruction of organic material can itself result in the generation of methane, the principal constituent of natural gas. Present-day examples are "marsh gas," "sewer gas," and "landfill gas." Some gas generated by bacterial action in the geologic past has been trapped in underground reservoir rocks and is commercially produced from wells drilled into such pools. However, it has been estimated that only about 5 percent of all natural gas produced originated in this way; the remaining 95 percent is the result of deep burial (see below). In recent years, there have been successful efforts to use sewer gas and landfill gas directly, including two landfill gas recovery projects operating in the Portland, Oregon, area.

Areas in which sediments have accumulated over long periods of time, usually measured in millions of years, are known as "sedimentary basins." In some basins, sediments (and the sedimentary rocks that they become) are tens of thousands of feet thick. As sediments accumulate, the original floor of the basin typically continues to warp downward so that the surface remains a basin and sediments continue to be deposited there. Even relatively slow rates of deposition can add up to a thick section of sediments over geologic time. For example, the accumulation of sediments at a rate of 1 inch (in.) per 100 years would result in a thickness of 1 foot (ft) in 1,200 years and 10,000 ft in 12 million years.

With the increased pressure of burial, the sediments are compressed and become sedimentary rocks. Gravel, cobbles, and boulders become "conglomerate," sand becomes "sandstone," silt becomes "siltstone," and clay becomes "claystone" or "shale." The term "shale" is sometimes used in the oil and gas industry to include all the fine-grained sedimentary rocks, that is, everything finer grained than sandstone. That's the way we will use it here.

Temperatures within the earth's crust increase with depth. Usually this increase is 1 or 2 degrees Fahrenheit (F) for each 100-ft increase in depth, although it can be much higher in some places such as young volcanic areas. Thus, in an area with an average surface temperature of 50° F and a temperature gradient of 1.5° F per 100 ft, the temperature at a depth of 10,000 ft would be 200° F.

As organic material in the sediments is progressively buried and heated, it slowly changes form. Finally, when a critical temperature is reached and held or exceeded over a sufficient period of time, part of the organic material is converted to droplets of oil or bubbles of gas. The longer the organic material is exposed to elevated temperature, the lower that temperature needs to be to cause the conversion. For example, it has been estimated that for burial of longer than 75 million years, a temperature of only about 150° F is required to begin the conversion to hydrocarbons; to begin conversion in less than about 20 million years, the temperature must be on the order of 200° F or more.

There is almost always some natural gas associated with underground oil accumulations, with the gas being either in a free state or dissolved in the oil or both. However, there are many "dry gas" accumulations, that is, pools containing gas only, with no liquid hydrocarbons present. This is sometimes due to the type of organic material originally preserved in the source rock. Woody plant remains tend to be converted to natural gas, while waxy plant material and fatty animal remains tend to become both oil and gas. Other dry gas accumulations are the result of another process (see below).

With continued increase of temperature or length of burial time beyond that necessary to begin conversion of source material to hydrocarbons, the conversion will continue within certain limits. Depending on the length of burial, as we discussed above, after the temperature increases beyond a range of 275° to 375° F, no more oil will be generated, but only gas; in fact, any oil still within the source rock will begin to break down into gas at and above these temperatures. This process explains the occurrence of many dry gas fields. Finally, and again varying with the length of burial, above temperatures ranging from 350° to 450° F, even natural gas generation will cease, and any remaining organic material will eventually become solid carbon.

All of the above assumes that the sedimentary rock contains enough organic material to generate significant amounts of hydrocarbons. This is not always the case. Some rocks are so barren of organic material that they can never become source rocks, regardless of their burial history.

Now that we have discussed the generation of oil and gas, we need to consider what happens to it.

RESERVOIR ROCKS

Under certain conditions, many kinds of rock can be both porous (having pore spaces available to contain fluids) and permeable (having pore spaces connected so that fluids can move through the rock) and can therefore be capable of serving as reservoir rock. These include any hard, brittle rock such as granite, limestone, basalt, chert, or hard shale that is extensively jointed or fractured. Limestone fossil reefs can be very porous and permeable because they may contain now-empty living spaces once occupied by the reef-building organisms. Other kinds of limestone (and its close cousin, dolomite) may be suitable reservoir rocks because of selective partial solution by water. However, on the West Coast, sandstone is by far the most common reservoir rock for oil and gas. The only commercial hydrocarbon production in the Northwest (at the Mist gas field in Oregon) is from sandstone reservoirs. Therefore, our further discussion of reservoir rocks will center on sandstone, but much of it will also apply to other porous and permeable rocks.

It is easy to imagine oil or gas wells as producing from underground caves or rivers or lakes full of the stuff. However, that is not the way it works. It is harder to visualize the little pores in the rocks underground that actually contain oil or gas. Let's try it this way. Imagine a 10-gallon (gal) bucket filled level full of marbles all of the same size. You can pour a little more than 2½ gal of water into that bucket full of marbles before the water spills over. Furthermore, you can put a screen or grate over the bucket and pour all the water out, except for a thin film around each marble. More than a quarter of the marble-filled bucket "reservoir" is pore space (porosity), and the water goes in and out readily, demonstrating that it is permeable (permeability).

In the above example, the size of the marbles, within certain limits, doesn't matter, as long as they are round and of the same size (well-sorted). Rounded sand grains, even as small as 0.1 millimeter (mm) or a little less in diameter, will give a similar result, except that there will be a greater amount of water retained as a film around the grains. The same sort of thing would result using gas or very "thin" (low viscosity) oil instead of water; with thicker (higher viscosity) oil, the effectiveness of the permeability will be reduced.

If the size of the marbles or sand grains varies greatly (poorly sorted), then the smaller ones will fill part of the voids (pores) between the larger ones, thereby reducing the porosity. If enough clay or silt particles are mixed with the sand grains ("dirty" sand), they can completely choke the pores and greatly reduce the effective porosity and permeability. Also, in nature, certain minerals such as calcium carbonate or silica can solidify in the pore spaces of sandstones, thereby partly or completely closing (cementing) them. Finally, if the grains are angular rather than round, the sharp corners will tend to project into what would otherwise be pore space if the grains were round, thereby reducing porosity.

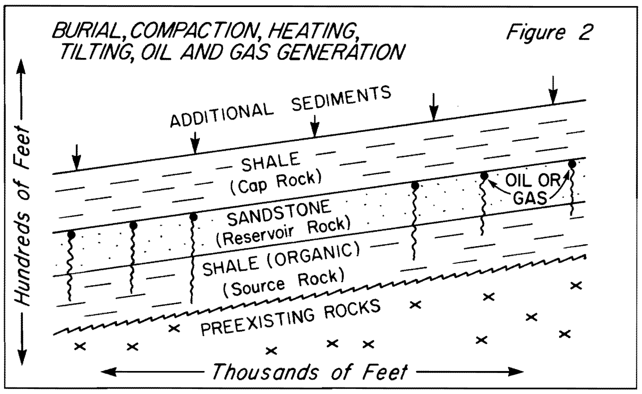
Our ideal sandstone reservoir rock then consists of well-sorted, well-rounded, clean, and uncemented sand grains. And while we are wishing, we would also like the sandstone to be nice and thick and to extend over many square miles. In real life, we seldom get ideal and gladly settle for adequate, if we can get it.

Suitable reservoir sandstones did not all originate as sand deposited in the sea. Sands deposited in such features as dunes, river bars, stream-channel fills, deltas, or alluvial fans can become reservoir rocks if the resulting sandstones are porous and permeable.

We left our source-rock discussion with oil and gas neatly generated into droplets or small bubbles but still within the source rock, mostly likely a shale. How does it get from there into the reservoir rock?

When sediments, including those that eventually become source rock, are deposited in an aqueous environment, they are completely saturated with water. With the pressure of burial, the sediments are progressively compressed, and water is squeezed from them. While sands typically lose only about 5 percent of their thickness this way, shales may be compressed as much as 40 percent. In addition to free water within the mass of sediments, some clays also contain chemically combined water. After gas and oil have been generated, it is thought that additional compression expells the finely divided hydrocarbon from the source rock along with some of the remaining water. In this way, oil and gas are slowly flushed into adjacent reservoir rock. The source rock can be below, above, or alongside the reservoir rock, just so long as the two are adjacent.

Reservoir sandstone is also saturated with water unless and until the water is displaced by something else. Because they are lighter than water, oil droplets or gas bubbles entering the water-filled pore spaces will work their way vertically upward through the permeable rock. If the reservoir rock is thick enough to extend up to the surface of the land or the floor of the sea, the oil and/or gas will escape there as a "seep." If the reservoir rock is covered by a layer of rock that is not permeable, the vertically buoyant movement of the hydrocarbons will stop at the boundary (Figure 2).



CAP ROCKS

Any rock layer that is not readily permeable to oil or gas can stop the vertical migration of hydrocarbons. In most sedimentary basins around the world, the most common effective seals, or cap rocks, for reservoir rocks are salt, anhydrite (calcium sulfate), and unfractured shale. Beds of salt and anhydrite usually result from long periods of evaporation; these are not important as cap rocks in West Coast oil and gas fields, so we shall limit our discussion to shale cap rock, including siltstone, claystone, and mudstone.

To be effective, cap rock must extend unbroken over the areas of hydrocarbon generation and of eventual accumulation, as well as any area between. Otherwise the hydrocarbons will work around the shale body and resume their vertical migration. Other things being equal, the thicker the shale body, the more likely it will be to continuously cover a large area.

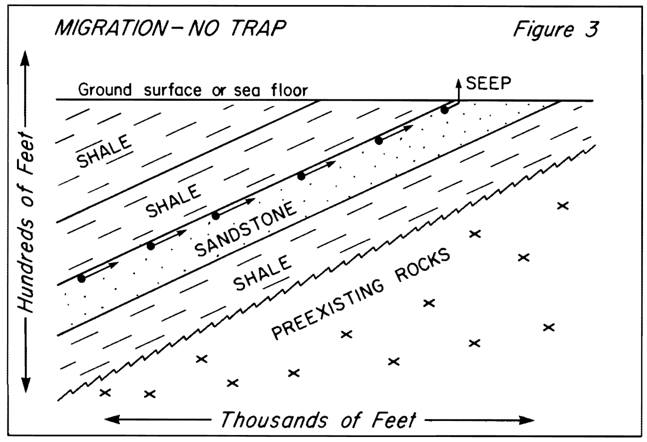
In order to be sufficiently impermeable to act as a seal, especially for natural gas, shale must have been compressed enough for most of the interconnected water-filled pore spaces to have been eliminated from the original sediments. Otherwise gas will rapidly diffuse and escape upward through such pores. On the other hand, the shale must not have become brittle enough to fracture readily under stresses and strains within the earth's crust.

We have talked about cap rocks in their capacity as a top seal on the reservoir rocks. However, for a thickness of hydrocarbons to accumulate, a seal (cap rock) must be present to prevent lateral movement also.

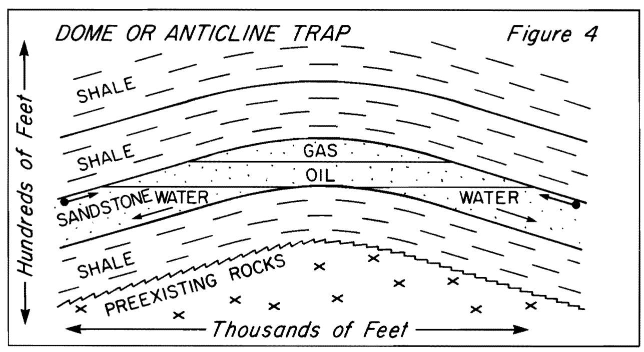
TRAPS

We think of the earth's crust as being more or less stable, at least between earthquakes and volcanic eruptions. In fact, over geologic time, Mother Earth has been very active in terms of movement. Consider, for instance, that sedimentary rocks containing the fossilized remains of sea creatures are present at or near the top of many peaks in the Rocky Mountains. As well as having been uplifted, parts of the crust have been shoved together, spread apart, downwarped, tilted, folded, and broken and offset along the breaks (faults). Almost all areas of the globe have been or currently are being subjected to one or more of these dynamic processes. Consequently, nearly all rock layers are tilted or otherwise deformed to some degree. Fortunately, in most cases, these movements take place so slowly that they are unnoticed by human beings.

We left our migrating oil droplets and gas bubbles stopped (momentarily) in the upper part of the reservoir rock at its contact with overlying cap rock. They cannot penetrate the cap rock vertically, but their buoyancy will continue to carry them laterally and upward at a slant under the contact. The hydrocarbons may continue their upward inclined migration to the surface of the ground or to the sea floor, where they will leak out as a seep (Figure 3). Or their upward migration may be stopped at some point by the configuration of the reservoir and cap rocks, and the hydrocarbons will accumulate in this trap.



There are many kinds of hydrocarbon traps. The easiest to visualize is a dome-shape trap, in which the underground reservoir rock and its overlying cap rock are arched up from all directions to an apex (or, as the geologist says, it dips in all directions down from the apex) (Figure 4). Hydrocarbons migrating upward in the reservoir rock just under its contact with the cap rock can go no higher than the top of the reservoir rock at the apex of the dome. Here, the hydrocarbons begin to collect. As they do so, the water previously in the pore space is displaced downward.

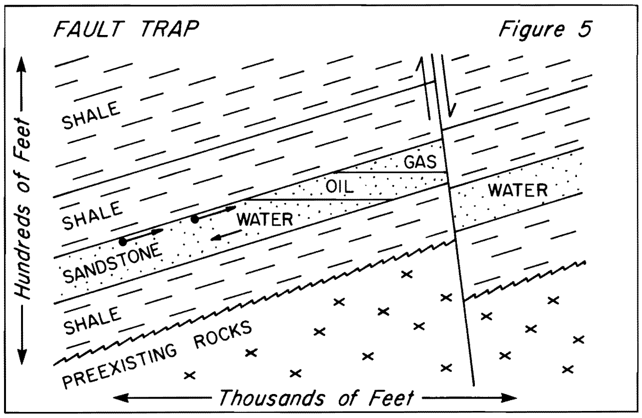


If both oil and gas are trapped, they will begin to segregate in the reservoir, with the lighter gas above the oil, which in turn will stay above the still heavier water. The quantity of hydrocarbons in the trap will increase as long as migration into it continues, until it is full and further additions spill out, or until it is ruptured or otherwise destroyed.

In a dome-type trap, the same cap rock that serves as the top seal over the apex dips down to or below the base of the hydrocarbon accumulation and therefore also serves as the lateral seal for the trap.

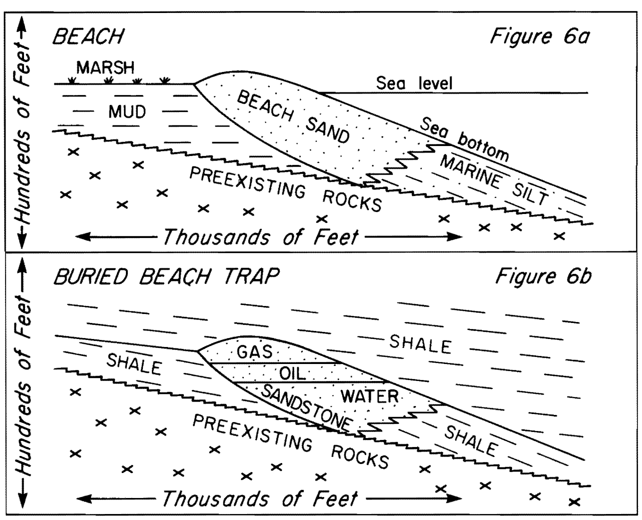
Folds in the rock layers that are convex upward (called anticlines) occur more commonly than domes, but the trapping process is similar (Figure 4).

Where the rock layers are broken along a plane and the rock on one side of the break is displaced relative to the other side, a fault trap can result (Figure 5). If the reservoir rock at the up-tilted (updip) edge on one side is offset against cap rock on the other side of the fault, then hydrocarbons migrating up to the fault cannot cross it. (Except at very shallow depths, faults do not normally stand open but are self-sealing because of the pressures at depth.) Hydrocarbons will then begin to accumulate at the highest part of the reservoir against the cap rock above the reservoir and laterally against the cap rock across the fault.



FAULT TRAP Figure 5

The segregation of different sediments during their deposition can later result in traps. For example, sand bars, sand beaches, sand-filled stream or tidal channels, and sand dunes may develop while mud (or silt or clay) is being deposited on one or more sides of them and, later, over their tops as well. After millions of years, those sands may have become potential underground sandstone reservoirs, with their updip edges sealed in the shale that the fine-grained sediments have become (Figures 6a and b).



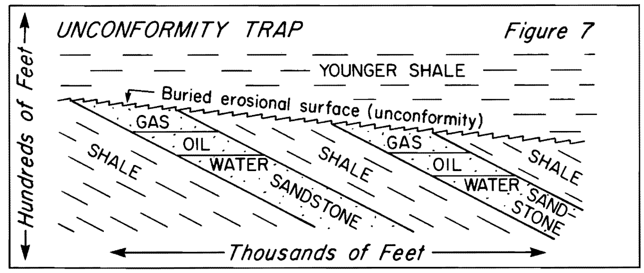
BEACH Figure 6a

BURIED BEACH TRAP Figure 6b

Some kinds of erosion followed by selective deposition and subsequent burial can also create traps. One example would be a stream valley that has been cut into shale bed rock, later filled with sand from the stream, then submerged along with the surrounding area, and finally covered by a thick layer of mud. The sand-filled channel could eventually become a potential underground sandstone reservoir with lateral seals of older shale on at least two sides and a top seal of younger shale. Another example would be tilted beds of alternating sandstone and shale eroded to a near-horizontal surface (an unconformity), with that surface later being covered with silt, clay, or mud (Figure 7). After further burial and compaction, the younger blanket shale could serve as a top seal, and the older shale beds could serve as lateral seals to the reservoir sandstones.

There are many other kinds of traps, including those caused by differential cementing of reservoir rocks or by differential fracturing of otherwise nonreservoir rocks. And, of course, there are combination traps resulting from the interaction between two or more trapping mechanisms.

On occasion, an unsuccessful exploratory well, known in the industry as a "dry hole," is drilled into a theoretically good trap containing adequate reservoir and cap rocks in a basin containing rocks that obviously generated hydrocarbons.



UNCONFORMITY TRAP Figure 7

SEQUENCE

Even if all the right physical features necessary for an oil or gas accumulation are present, it comes to naught if they did not develop in the right sequence. For example, when hydrocarbons are first generated, if there is no reservoir rock nearby, they may remain dispersed in impermeable source rock. When hydrocarbons migrate into reservoir rocks, if there is no cap rock already in place, they may be lost to the surface. This would also be true if no trap exists along the route at the time of migration, or if a preexisting trap has been breached by erosion, faulting, or adverse tilting of the rocks. And, of course, even if all of the parameters otherwise necessary for hydrocarbon accumulation are present, if the potential source rocks have not been buried deeply enough or long enough, the trap is likely to be barren.

So in exploring for oil and gas accumulations, as in cake making, just having all the ingredients does not assure success. In either case, if they are not combined and baked properly, the result will be less than desirable.

EXPLORATION METHODS

How do we go about determining if a given unexplored or relatively unexplored area has oil or gas potential? Fortunately, much can be learned from the surface.

First, we must determine if the area is in a sedimentary basin. Typically, at least some of the sedimentary rock layers of a basin are tilted up and exposed around the edges. In arid climates, bed rock may be exposed and accessible for inspection over broad areas. In wet climates such as that of western Oregon, the bed rock is usually deeply weathered and covered with soil and dense vegetation, and outcrops of bed rock are often limited to stream cuts and road cuts. Inspection of even small, scattered outcrops will usually tell us quickly whether or not they are part of a sedimentary basin.

At least some of the rocks buried thousands of feet below the surface in the deeper parts of the sedimentary basin may be represented in basin-edge surface outcrops. Close examination of these outcrops in the field can give the experienced geologist a fair idea as to whether the basin possibly contains hydrocarbons. Later, physical and chemical laboratory tests of rock samples taken from the outcrops can quantitatively determine such things as porosity and permeability and the type, quantity, and stage of transformation of contained organic matter.

The ages of rock layers may be determined if fossils are present. The relationship of rocks in different areas can often be determined on the basis of their ages. Especially important are small fossils called microfossils, which are fossil shells of tiny aquatic animals and some fossil plant remains, such as pollen, that generally require a microscope for identification. These can sometimes be matched directly with microfossils taken from well-bore drill cuttings, since many of them survive the drilling action that usually destroys larger fossils. Sometimes the age of a rock can be determined from the relative abundance of certain radioactive elements and their isotopes or from the degree of chemical alteration of some minerals.

Basin-edge sedimentary rock outcrops are not necessarily representative of all of the rocks concealed in the subsurface in the central part of the basin. Some of the sediments deposited deeper in the basin may not have been deposited around the edges; periods of uplift and subsequent erosion may have taken place, resulting in the removal of relatively more rock near the edges. Furthermore, it often happens that one kind of sediment was deposited near the edge at the same time that another kind of sediment was deposited in the central part of the basin.

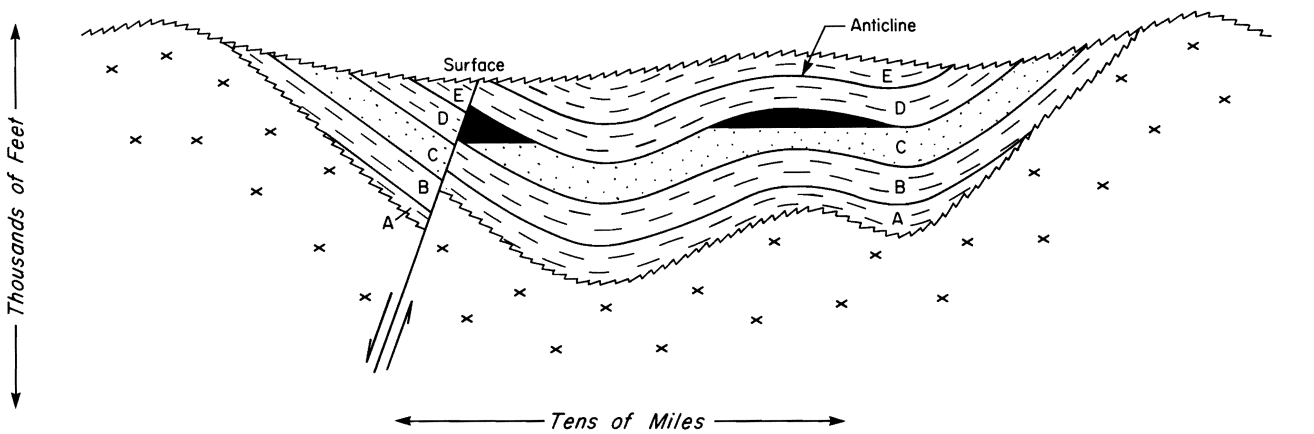
Nevertheless, rock outcrops generally provide good clues as to whether (1) potential source rocks are present in the basin and whether they have at some time been buried deeply enough and long enough to have generated hydrocarbons, (2) potential reservoir rocks are likely to be present, and (3) potential cap rocks exist.

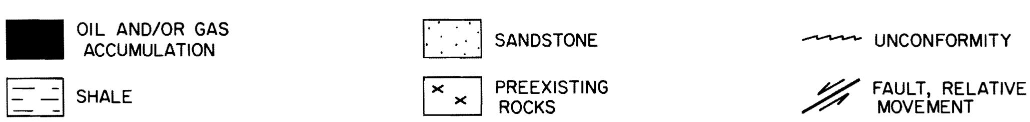
Surface-rock outcrops are not necessarily limited to the edges of sedimentary basins. However, outcrops in the central part of a basin, if they occur, are usually of rocks younger than those exposed around the basin edges. Because they are at the surface, these rocks are probably not objectives for drilling. However, the direction and angle of tilt of these exposed rock layers can be measured from place to place, and the presence of faults and folds can often be detected. In this way, the overall geometric shape or structure of the rock layers can be constructed. Folds, tilted fault blocks, and other potential hydrocarbon trap shapes mappable in outcrops can be the surface expression of those kinds of traps in older, favorable rocks at depth (Figure 8). In such case, all we have to do is drill into it and — bingo! — we're in business. Sometimes it even happens that way!

More often, it does not work that way. The folding or faulting mappable at the surface may have taken place so recently that the hydrocarbons migrated before the trap formed. Or, the favorable characteristics we saw in the older rocks in outcrop at the edge of the basin do not extend as far as our drill site area. Or, the

STRUCTURES MAPPABLE ON SURFACE OUTCROPS AND PERSIST AT DEPTH

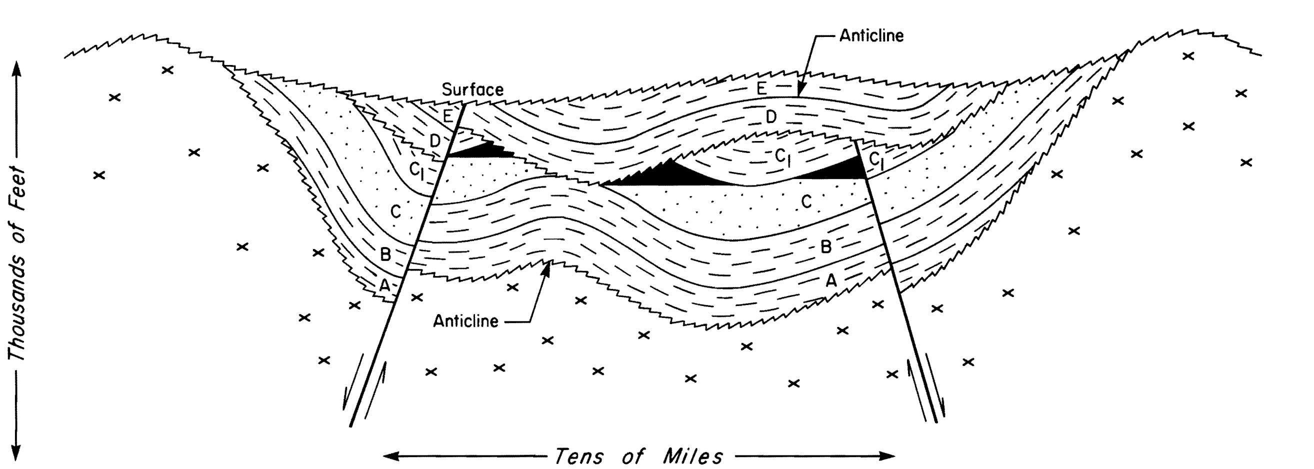
Figure 8





DEEP FEATURES PARTLY OBSCURED BY BURIED EROSIONAL SURFACE (UNCONFORMITY)

Figure 9



older rocks may have been folded or faulted and then uplifted and beveled off by erosion prior to deposition of younger sediments now exposed on the surface, so that surface structures do not coincide with deep subsurface structures (Figure 9).

We may have outcrops between the central basin and the basin edge in which the relationships between various rock units can be partially seen, but even this is not likely to pinpoint a subsurface trap.

Oil or gas pools, especially those full to overflowing, may leak a little. This may result in an oil or gas seep at the surface, which can be a very good sign. On the other hand, a seep may be an indication of no trap at all, as we discussed earlier.

In surface geologic mapping, or field geology, topographic maps are a necessity. Aerial photographs, especially in stereoscopic pairs (for a three-dimensional effect), and remote-sensing imagery from satellites can be very useful. If available for the area of interest, regional geologic maps and reports such as those published by the Oregon Department of Geology and Mineral Industries and the U.S. Geological Survey can provide a great head start toward understanding the geologic history of the area and in detailed mapping.

In addition to careful geologic surface mapping, what can we do to increase our chances of finding a commercial hydrocarbon accumulation in the subsurface when we drill our exploratory well, called a wildcat?

Surface and near-surface physical and chemical measurements can be made of phenomena that are affected by subsurface conditions. Measurement of such things as differences in gravity, magnetic field, heat flow, radioactivity, natural or induced electrical currents, and response to induced seismic waves is called geophysical surveying. Measurement of variations in the concentration of chemical elements or hydrocarbons in surface or near-surface materials or organisms is called geochemical surveying.

Favorable results from geophysical or geochemical surveys can certainly enhance our chances of success in drilling. Sometimes our drilling site may be picked primarily from such results. However, these surface measurements of subsurface conditions are indirect and are without exception dispersed and distorted to some degree by the intervening rock. The costs of such surveys range widely; for example, a magnetic survey of an entire basin may cost no more than a seismic survey of a few square miles. Geophysics and geochemistry should be considered in every exploration program but must be planned carefully; the costs can quickly add up to more than the cost of drilling the ensuing wildcat.

When an exploratory hole has been drilled into the older rocks in the basin, we get some direct information on the subsurface, assuming we have access to the well records. If the well was completed as an oil or gas producer, it is likely that other hydrocarbon accumulations will be found in the basin. If the well was a dry hole, that is, if it was not successful in finding commercial quantities of hydrocarbons, it does not necessarily mean that the entire basin is barren. At least 10 dry holes were drilled in Saudi Arabia before a commercial oil field was found; more than 200 dry holes were drilled in Oregon before the Mist gas field was discovered. A field, incidentally, consists of one or more pools in the same general area.

In either case, descriptions or our own examination of rock samples taken from the well will be very useful. In addition, graphic representations called logs, of downhole measurements of electrical, radioactivity, sonic or acoustic velocity, drilling rate, and other characteristics of the rocks penetrated by the well should be available. Electric logs, sonic logs, and gamma-ray logs are just a few of the types of logs generated during a drilling program.

From the borehole samples and logs, the depths, thicknesses, and types of rocks can be determined, as can the kind of fluid contained in reservoir rocks (salt water, fresh water, oil, or gas). From a dip log, or dipmeter, the angle and direction of tilt of the rock layers can be calculated.

With information from the hole, events on nearby geophysical surveys can be better calibrated to subsurface features, and rocks in the subsurface can be better related to rocks in outcrops elsewhere. If a number of wells have been drilled, and if the information from these wells is available, maps and cross-sections showing the shape or geologic structure of various layers of rock in the subsurface can be constructed from the wells. Geophysics can be very useful in the interpretation of the structure between and beyond wells, and the surface geology can also be helpful. From such subsurface depictions, possible hydrocarbon traps may be identified.

When we think that all of our information indicating a trap is conclusive enough, then we may recommend that a wildcat well should be drilled to test the prospect. But first we need to talk about money.

ECONOMICS

My education on the economics of oil and gas exploration began when I was an eager young geologist for a sizable oil company. After a long session with the Chief Geologist, when I was pushing hard to get my favorite prospects drilled, he said, "Bruer, you have the mistaken idea that this company is in business to find oil and gas. It is not. It's in business to make money." Doubtlessly, the stockholders heartily agreed.

The economics of oil and gas exploration is a very complex subject. I intend to point out just a few of the more obvious considerations.

We will drill the wildcat well on our prospective underground trap (our "prospect") only if we think it is good business to do so — that is, if by drilling this prospect and others like it, we can pay the costs of all our operations and still make a profit (and thereby stay in business). We need to make a careful evaluation of these costs and of how much oil or natural gas may be recovered from our prospect if it should prove to be productive.

In addition to the potential quantity of oil or gas, we need to consider quality. Natural gas may contain more or less inert contaminants such as nitrogen or carbon dioxide that reduce its heating value and therefore its price. Or, it may contain noxious contaminants such as hydrogen sulfide (rotten egg gas), which require expensive treatment to remove. Thick, heavy, low-gravity crude oil can be difficult to produce and transport, and it will yield a higher percentage of lower priced refined products, such as residual fuel oil, than products from lighter, high-gravity crudes. Contaminants in crude oil, such as sulfur and sulfur compounds, can be removed by more expensive refining processes; if they are not removed, the resulting refined products will be less desirable and lower in price.

The revenue from the saleable products of an oil field must pay for (1) the cost of exploration, possibly including many dry holes prior to discovery; (2) the cost of lease acquisition, lease rentals, and royalty payments; (3) the cost of drilling, testing, completing, and equipping the discovery well and the other producing wells necessary to drain the field; (4) the cost of pumping or otherwise lifting and gauging the oil; (5) the cost of gathering the oil from all the wells to a shipping point; (6) the cost of disposing of waste water produced with the oil; (7) the cost of shipping the oil to a refinery, whether by pipeline, tanker, barge, rail, or truck; (8) the cost of refining; (9) the cost of distributing the refined products; (10) the cost of retailing the products; and (11) taxes and the cost of accounting, management, depreciation, maintenance, repair, and other overhead.

For natural gas, steps 7 and 8 above do not apply, but at that point in handling gas, it will probably have to be treated to remove excess water vapor and any liquid hydrocarbons. It will be odorized for safety purposes (most natural gas is odorless as well as colorless and tasteless), and it will probably have to be compressed at least once to push it through the pipeline to market. As you can see, it takes more than a few thousand barrels of oil or a few million cubic feet of natural gas to constitute a commercial hydrocarbon accumulation, even under the best of circumstances.

Obviously, we don't want to drill a wildcat well that costs $2 million in order to possibly find $1 million worth of oil or gas. It is not even good economics to drill a $1 million wildcat to possibly find $2 million worth of oil or gas. Now that is not a "put on"; because of that word, "possibly," the risk has to be factored in.

Statistically, one wildcat in six drilled in an attempt to find a new field in the United States will find some commercially producible oil or gas. However, the odds are about 1 in 150 that a large field of more than 10 million barrels of recoverable oil or 57 billion cubic feet of recoverable natural gas will be found.

Now, back to our $1 million wildcat to possibly find $2 million worth of hydrocarbons: Statistically, we will have to drill six similar wildcats, five of which will be dry holes, for a total drilling cost of $6 million to find our $2 million field.

Let us consider very expensive wildcats, such as those drilled offshore in the Arctic Ocean or in any very deep or very difficult drilling area. If we assume the wildcat will cost $5 million just to drill, then we already know our potential field had better be a large one. Statistically, it will take 150 wildcats to find one large field at a drilling cost alone of 150 multiplied by $5 million, or $750 million! For all practical purposes, in such areas it does not make economic sense to drill a wildcat to try to discover a field containing less than about $1 billion worth of oil and/or gas. Fortunately, there are many less difficult and less costly areas in which to explore.

Other parts of the economic mosaic above can render our prospect noncommercial. We may estimate that the prospect contains $30 million worth of natural gas. Great! But, it may be so far out in the boondocks that it would cost $40 million to build a pipeline to get the gas to market.

Or the mineral owners may ask for exorbitant lease bonus or rental payments. The cost of leasing on exploratory prospects, like the cost of wildcat drilling, also has to be factored for risk. That is, when evaluating a prospect, lease costs should be multiplied by the statistical number of prospects that must be leased as well as drilled before one is successful (six or 150 or whatever). For example, in a 10,000-acre lease block on a potential large field prospect, an additional cost of $1 per acre factored for risk (times 150) would require that the potential field contain a value of $1.5 million more in recoverable oil or gas than otherwise to warrant going ahead with leasing and drilling the prospect. Many a drilling plan has been canceled because of leasing problems.

We may evaluate our prospect, including weighting it for risk, and conclude that we can make a profit by drilling it and others like it. In fact, we may calculate that the profit left over after paying local, State, and Federal taxes on our gross revenue will about equal the amount of those taxes. But then, perhaps, the Feds may eliminate our tax deduction for intangible drilling costs, and/or the state doubles its severance tax, and/or the county raises its mineral tax, so that the net effect is to double our taxes. Goodbye profit, so long prospect. Of course, a reduction in the price of crude oil or natural gas can have a similar effect. On the other hand, increased prices for oil or gas can make economically marginal prospects profitable.

And that's enough about economics to give you a general idea.

CONCLUSION

We have covered the broad question of "Why is an oil or gas field" with some very general answers. If you want to get deeper into the subject, you should probably start with any good beginning general geology textbook, preferably an edition no older than 10 or 12 years. Then, if you're still interested, you can delve into one or more of the many books on petroleum geology.

More fields will be discovered in the Northwest in coming years. I hope that this article has dispelled the mystery of oil and gas exploration and that it will help you to enjoy following the action. □

Gorda Ridge reports released

Six reports on the geology and biology of the Gorda Ridge have been prepared by the Oregon State University (OSU) College of Oceanography and released as open-file reports by the Oregon Department Geology and Mineral Industries (DOGAMI). The Gorda ridge is a sea-floor spreading center off the coast of southern Oregon and northern California that lies within the U.S. Exclusive Economic Zone (EEZ). The six newly released documents report the results of research on the benthic (ocean-bottom) ecology, heat flow, trace-metal chemistry, radon gas concentration, seismic activity, and mineralogy of the ridge area.

The reports were commissioned by the joint Federal-State Gorda Ridge Task Force in March 1985. The Task Force, which was formed in 1984, was charged with conducting a technical analysis of the economic and environmental implications of leasing the Gorda Ridge for the mining of polymetallic sulfide minerals. Funding was provided by the U.S. Minerals Management Service.

Analysis of Benthic Epifaunal and Infaunal Community Structure at the Gorda Ridge (Open-File Report O-86-11) was written by Andrew G. Carey, Jr., David L. Stein, and Gary L. Taghon. The 34-page report discusses the invertebrate and fish fauna observed on film shot in the vicinity of the ridge during 1984 and 1985.

Heat-Flow Results from the Gorda Ridge (O-86-12), by Dallas Abbott, describes on 10 pages the results of heat-flow measurements made in the sediment-filled southern third of the ridge, the Escanaba Trough.

Studies of Trace Metals and Active Hydrothermal Venting on the Gorda Ridge (O-86-13), 36 pages long and written by Robert W. Collier, Scott H. Holbrook, and James M. Robbins, discusses the use of trace-metal concentrations in conjunction with hydrography and turbidity to identify hydrothermal vent plumes on the Gorda Ridge.

Radon-222 as a Real-Time Tracer of Hydrothermal Activity on the Gorda Ridge (O-86-14) is 19 pages long. In it, author David Kadko documents the radon concentrations in hydrothermal plumes located over the Gorda Ridge during the summer of 1985.

Ocean-Bottom Seismometer Measurements on the Gorda Ridge (O-86-15), by L. Dale Bibee, is a 25-page report discussing seismic activity observed on the southern Gorda Ridge and comparing the seismicity to results obtained on the southern Juan de Fuca Ridge.

Hydrothermal Sulfides, Breccias, and Greenstones from the Gorda Depression (O-86-16) describes the mineralogy and chemical composition of samples dredged from a fault scarp along the Blanco Fracture Zone. Authors of the 31-page report are Roger Hart, Douglas Pyle, and James Robbins.

All reports are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The price for each report is $5. Orders under $50 require prepayment. □

In Memoriam: S. Kyle Huber

S. Kyle Huber, a member of the Portland law firm of Weiss, DesCamp, Botteri, and Huber, died at his home on June 6, 1986. Born on May 24, 1948, in Port Arthur, Texas, Huber received his bachelor's degree in economics from Tulane University in 1970 and his law degree from South Texas College of Law in 1975. Throughout his professional career, Huber worked in and was closely associated with the oil and gas industry. He worked with Texas Eastern Corporation of Houston, concentrating in natural gas regulatory matters from 1973 through 1976. In 1976 he and his family moved to Portland, where he became Assistant General Counsel to Northwest Natural Gas Company. He remained in that position until 1979, during which time he also acted as General Counsel to the gas company's geothermal resources subsidiary, Northwest Geothermal Corporation. In 1979 Huber left the gas company for the private practice of law in which he concentrated almost exclusively in natural resources law, particularly concerning oil and gas, geothermal, coal, and other minerals, including lode and placer mining.

In addition to being a member of the Oregon, Texas, and American Bar Associations, Huber was a founding member and first president of the Northwest Petroleum Association and was a member of the Northwest Mining Association, the American Association of Petroleum Landmen, the Pacific Coast Gas Association, the Geothermal Resources Council, the Western Oil and Gas Association, and the Minerals Committee of the Portland Chamber of Commerce.

Huber was an adjunct professor of law at the Northwestern School of Law, Lewis and Clark College, in 1983, where he taught oil and gas law. He also authored an article in "Landman," published by the American Association of Petroleum Landmen, entitled "Pacific Northwest: Recent Legal Developments," as well as authoring "Legislative Developments in Energy and Environmental Law" in 1983 for the Oregon State Bar Continuing Legal Education series.

Kyle will be missed by his friends and colleagues. Those of us who had the pleasure of knowing and working with him will remember his integrity, warmth, enthusiasm, and professional competence which he brought to his interactions with others. He is survived by his wife, Betsy, and his three children, Dallas, Kellan, and Will.

— James P. Draudt,
Weiss, DesCamp, Botteri and Huber,
Attorneys at Law,
Portland, Oregon

Luscher appointed new BLM state director

Charles W. (Bill) Luscher has been appointed to succeed retiring William G. Leavell as State Director for the Oregon/Washington office of the U.S. Bureau of Land Management (BLM). Leavell had served in that capacity for the last six of his 34 years in Federal service.

Luscher, a native of Libby, Montana, was graduated from the University of Idaho College of Forestry in 1954 and received a Master of Natural Resources Administration degree from the University of Michigan in 1967. He has held positions in BLM offices in Washington, D.C., Colorado, and Nevada; most recently, as State Director in New Mexico.

He has also served with the BLM Resource Management Team under the U.S. AID Program in Nigeria and participated as a BLM range specialist in a cultural exchange with the Soviet Union. In 1976, the Department of the Interior honored Luscher with its Honor Award for Meritorious Service. □

BLM releases geochemical data on southeast Oregon

A report on geochemical data from parts of southeastern Oregon's Harney and Malheur Counties and southwest Idaho's Owyhee County is available in several offices of the U.S. Bureau of Land Management (BLM).

The report includes analyses of 376 sediment and 65 rock-chip samples collected in an area totaling 220,000 acres. The samples were analyzed for 30 metals. The study was conducted by BLM's Oregon State Office in Portland and the Western Field Operations Center of the U.S. Bureau of Mines (USBM) in Spokane, Washington. BLM will use the data to assess the mineral resource potential of the survey areas as part of the studies leading to recommendations for wilderness suitability.

The report is available for examination in the following BLM offices: BLM Public Room, 14th floor, 825 NE Multnomah St., Portland, Oregon; BLM Vale District Office, 100 Oregon St., Vale, Oregon; BLM Boise District Office, 3948 Development Ave., Boise, Idaho. It is also on file at the USBM Western Field Operations Center, 360 E. Third Ave., Spokane, Washington. □

Geologist Nolf honored in Bend

Bruce O. Nolf, geology instructor at the Central Oregon Community College in Bend, has become the second recipient of the college's Distinguished Professor award.

In his recommendation to the college's Governing Board, President Fred Boyle praised Nolf for his community service, his geologic research in central Oregon, and his efforts toward keeping his instruction "on the cutting edge of geology."

Nolf is a graduate of the University of Iowa (B.S.), the California Institute of Technology (M.S.), and Princeton University (Ph.D.). □

Northwest miners honored

Three Pacific Northwest mining firms were honored by Federal agencies recently for their environmentally sensitive, safe, and efficient operations on Federally administered mineral lands.

Philip J. Sali, president of Columbia Asphalt and Gravel, Inc., Parker, Washington, and John Wisch of the Washington Irrigation and Development Company, Centralia, Washington, accepted awards from the U.S. Bureau of Land Management. The USDA Forest Service presented a similar award to Max Buckner and Irv Lamb of the Black Raven Placer Group located in northeastern Oregon.

The awards were presented in recognition of the willingness and cooperation of the operators to go beyond government requirements and for demonstrating a high level of concern for environmental and public values. □

Notice of change

During the next one month or two the mailing of *Oregon Geology* will undergo some significant — and we hope beneficial — changes. The mailing itself will be taken over by a mailing service outside the Department, and the maintenance of the mailing list will be handled with the help of a computer.

Please bear with us, if some problems occur during the transition. Let us know soon if you do not receive your magazine or if your address should not be quite correct. That address, by the way, will include a code number whose last four digits will tell you the expiration month and year of your subscription. Please take note of it as a timely reminder to renew! *— The editors*

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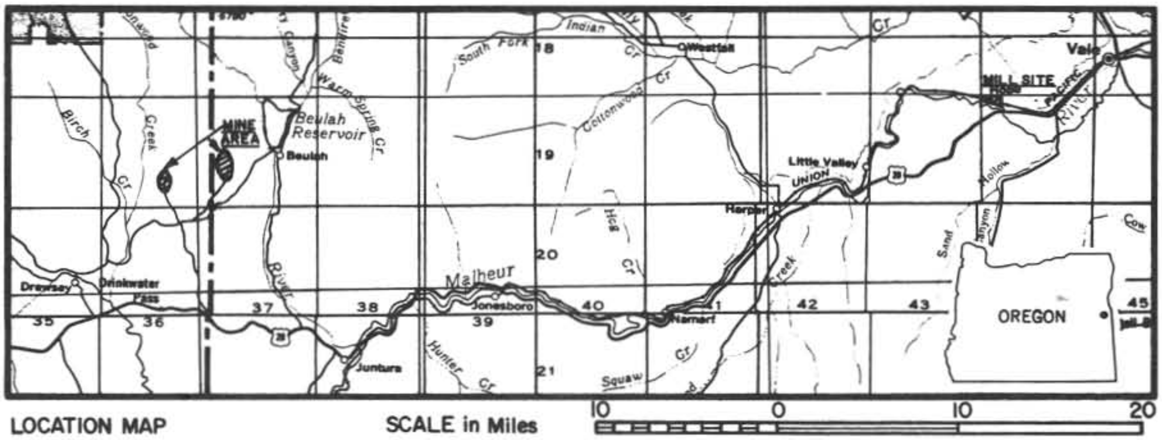

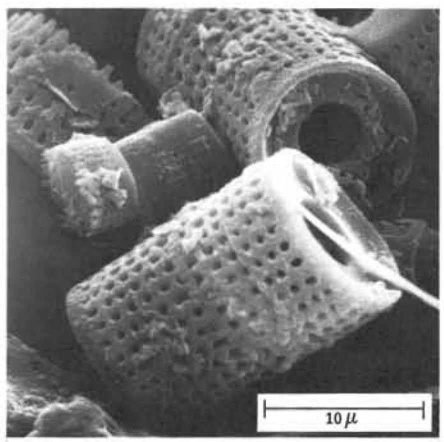

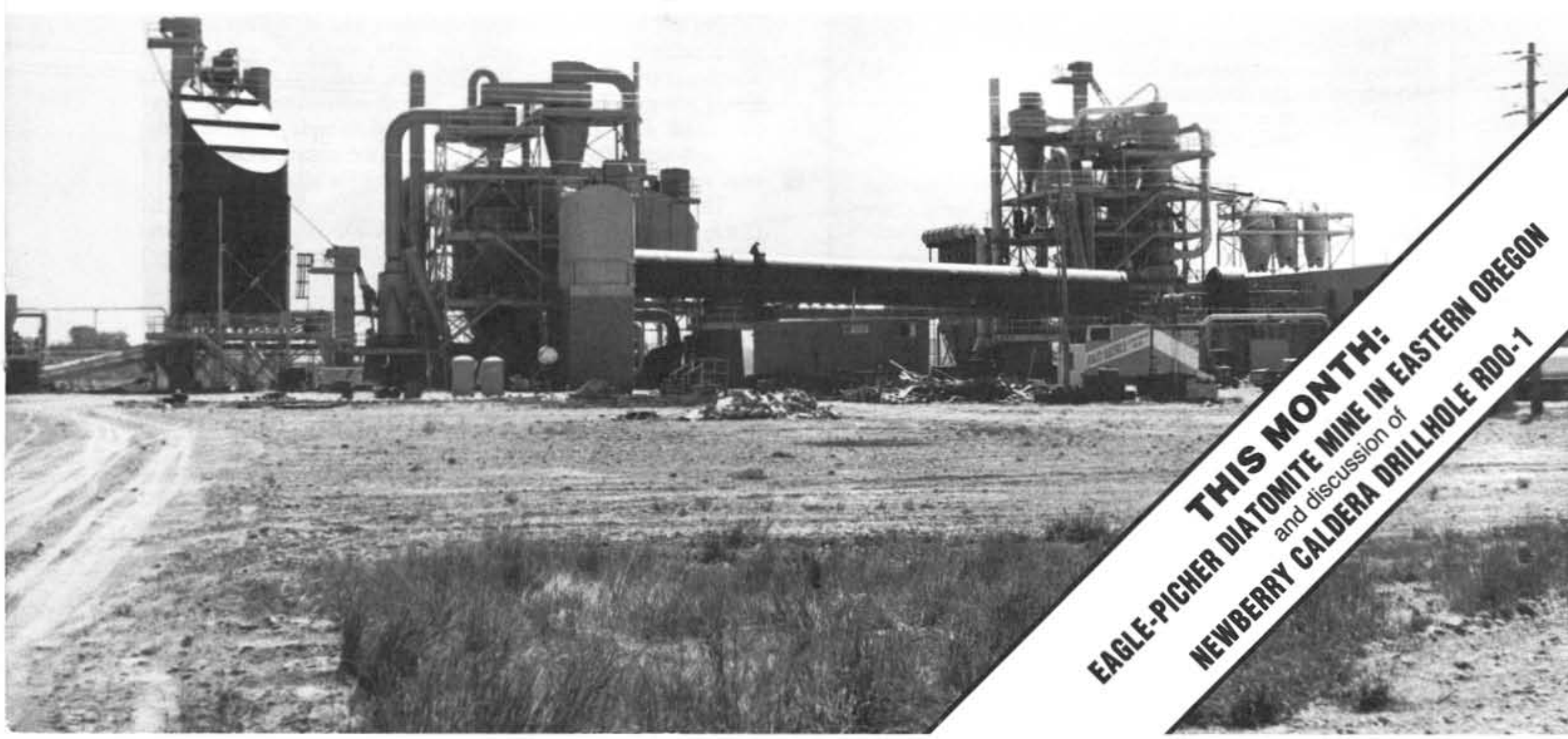

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and discussion of
NEWBERRY CALDERA DRILLHOLE RDO-1

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Information for contributors

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

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

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

COVER ILLUSTRATION

On August 18, 1986, a new diatomite mine and processing plant was dedicated near Vale, Oregon. Article describing this venture of Eagle-Picher Industries, Inc., begins on page 108. Illustration shows location map of the plant and its mining sites, view of the processing plant, and scanning electron photomicrograph of *Melosira granulata* diatoms.

OIL AND GAS NEWS

Results of Columbia County lease sale

The lease sale was held July 23 in St. Helens, Oregon. Columbia County offered 68,863 acres located throughout the county. A total of 19,070 acres were sold for a bonus of $133,405. The high bid was $70 per acre by ARCO for a 640-acre parcel, no. 321 in sec. 34, T. 6 N., R. 5 W.

The city of Clatskanie offered 572 acres of which 440 acres were sold with a high bid of $1.00 per acre by Ed Dunn.

Additional information is available from the Columbia County Board of Commissioners, phone (503) 397-4322.

ARCO begins drilling at Mist Gas Field

ARCO spudded Columbia County 14-23 in the Mist Field on August 5. The well is located in SW¼ sec. 23, T. 6 N., R. 5 W., Columbia County, Oregon. This is permitted as a 2,450-ft test.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
375	ARCO Columbia County 31-8 009-00212	NE¼ sec. 8 T. 6 N., R. 5 W. Columbia County	Application; 3,200.

□

Central Oregon geochemical survey released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a geochemical survey of a 425-square mile area east of Madras, *Mineral Assessment of the Southwest Quarter of the Stevenson Mountain 30- by 60-Minute Quadrangle, Jefferson and Crook Counties, Oregon.* The release is DOGAMI Open-File Report O-86-4, by J.J. Gray and G.L. Baxter (DOGAMI) and R.O. Van Atta (Portland State University).

The survey identifies several areas that would justify more intensive exploration efforts for hot-spring-type gold and other metal deposits. Breccia pipes, bleached zones, jasperoids, hot springs, sinter, and anomalous metal values were found within the study area. Analyses identified such ore minerals as arsenopyrite, azurite, cerussite, cinnabar, and malachite in gold-pan concentrates.

For the study, 416 stream-sediment and rock-chip samples were collected and assayed for eight elements, gold, silver, arsenic, copper, mercury, molybdenum, lead, and zinc. The published report consists of a 69-page text with numerous illustrations and data tables, a geologic and sample-location map, element-abundance maps for each of the assayed elements, a land status map, and detailed data tables for all samples.

The report is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, Portland, OR 97201. The purchase price is $10. Orders under $50 require prepayment. □

Correction

The following sentence was inadvertently omitted from last month's feature article ("Oil and Gas Exploration for the Nongeologist," by Wesley G. Bruer):

"Many thanks to reviewers H. Jack Meyer, Dena Nelson, Dennis Olmstead, D. Brian Williamson, and David Williamson."

The error was ours, and we apologize for it.

— *Editor*

Lithology and hydrothermal alteration of drill hole RDO-1, Newberry caldera, Oregon

by Terry E.C. Keith[1], Marshall W. Gannett[2], John C. Eichelberger[3], and Albert F. Waibel[4]

ABSTRACT

Lithologies penetrated by Sandia National Laboratories drill hole RDO-1 are correlative with those encountered by U.S. Geological Survey (USGS) Newberry 2 drill hole located 0.5 kilometers (km) to the northwest of RDO-1. Minerals produced by hydrothermal alteration are similar in both holes, but distribution with depth shows that higher temperatures were reached at a shallower level in RDO-1 as compared to Newberry 2. An aquifer penetrated by RDO-1 between 379.5 and 397 meters (m) induced artesian flow of water with temperatures in excess of 158° Celsius (C). This hot-water aquifer in RDO-1 correlates with the 100° C temperature maximum at 415 m in the upper part of Newberry 2. Hot water may flow upward from the ring fracture southeast of RDO-1 and spread laterally into permeable layers within the caldera; however, RDO-1 appears to be more directly in the path of the hot-water aquifer than Newberry 2.

[1]U.S. Geological Survey, Menlo Park, California.
[2]Columbia Geoscience; now with Oregon Department of Water Resources, Salem, Oregon.
[3]Sandia National Laboratories, Albuquerque, New Mexico.
[4]Columbia Geoscience, Hillsboro, Oregon

INTRODUCTION

RDO-1 was drilled to a depth of 424 m by Sandia National Laboratories, using mud rotary drilling methods. Drilling began on September 16 and ended on October 20, 1983. The hole was sited at an elevation of 1,969.0 m, approximately 0.5 km southeast of the USGS drill hole Newberry 2 (N2) (Figure 1).

Cuttings were collected from either 3- or 6.1- m intervals as drilling progressed and were logged at the drill site using a binocular microscope. A split of the cuttings was further studied in the laboratory by binocular microscope examination and petrographic and X-ray diffraction techniques. Detailed mineralogical studies were conducted on selected samples using a scanning electron microscope equipped with an X-ray energy dispersive analyzer.

Temperature data and some of the drilling history have been reported by Black and others (1984) and are summarized here. Maximum measured temperature in the well was 158° C at the 350.5-m depth two days after circulating mud; temperatures were not measured below 350.5 m at this time because the temperature probe failed. Between 379.5- and 397-m depth, the well penetrated an aquifer with a temperature in excess of 158° C and sufficient hydrostatic pressure to cause the well to dis-

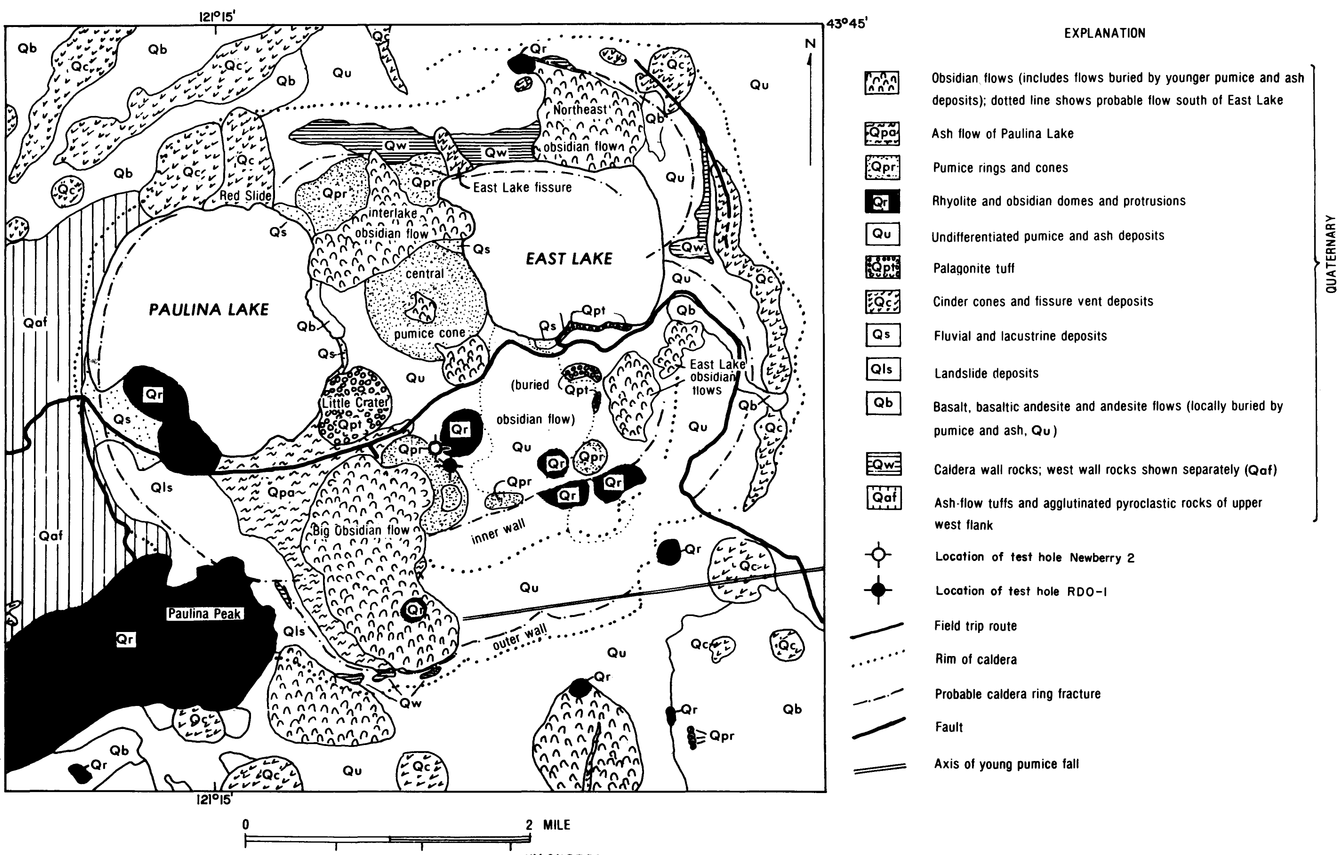


Figure 1. Geologic map (modified by Black and others, 1984, from MacLeod and Sammel, 1982), showing locations of the RDO-1 and N2 drill holes at Newberry caldera, central Oregon.

charge at the surface at a rate of approximately 340 liters per minute. Black and others (1984) suggest that the temperature of the main fluid entry of the aquifer may be in excess of 170° C.

LITHOLOGIC DESCRIPTIONS

Lithologic descriptions for RDO-1, except for the lowest unit, are given in Figure 2 and are not repeated here.

The lowest unit, a pumice and lithic tuff breccia extending from 328.6 to 424 m, appears to be the same as the pumiceous sand and gravel unit and the pumice lapilli tuff and lithic breccia unit of N2 (MacLeod and Sammel, 1982) (Figure 3). The core samples of N2 show similar textures and relative amounts of pumice fragments, pumiceous tuff matrix, and lithic fragments including mostly aphanitic to porphyritic mafic volcanic rocks. Clast sizes in N2 cores range from less than 1 millimeter (mm) to much larger than the core diameter of 6 centimeters (cm) (probably boulders). In RDO-1, six stratigraphic subdivisions have been recorded for the pumice and lithic tuff breccia unit on the basis of binocular examination of cuttings (Gannett and

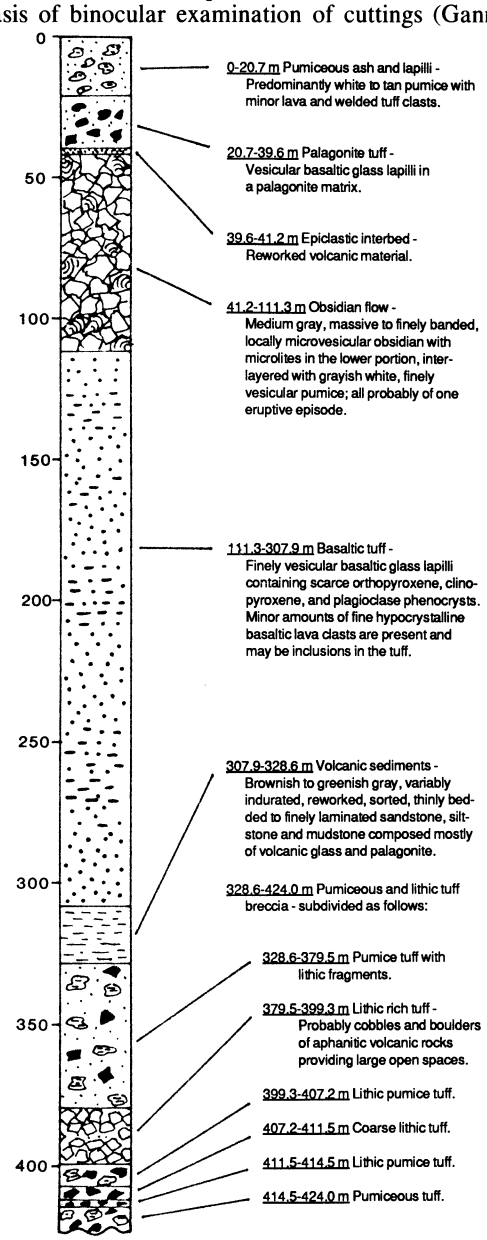


Figure 2. Lithologic log for drill hole RDO-1 (after Gannett and Waibel, 1983).

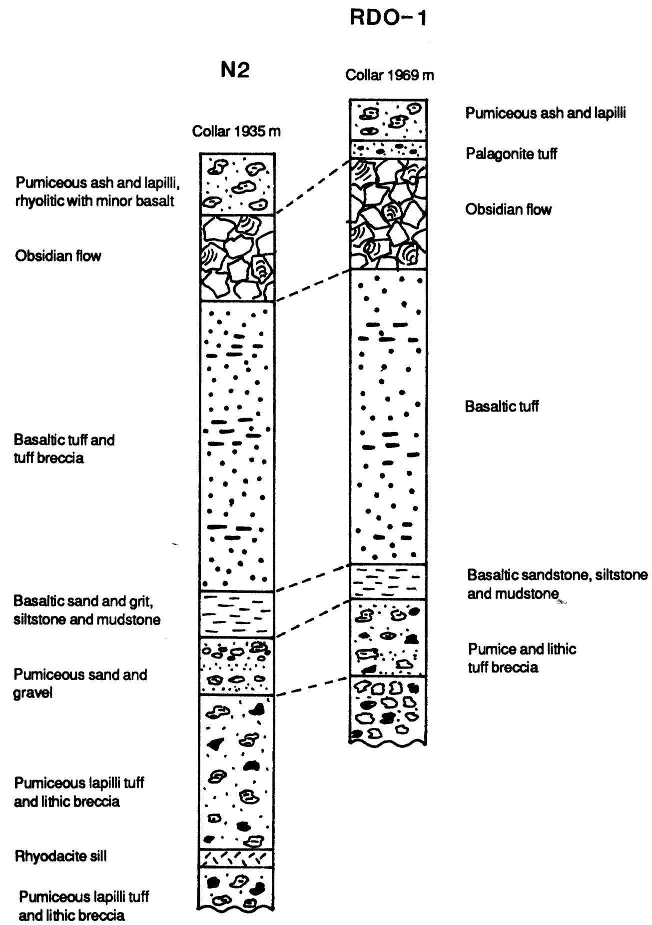


Figure 3. Lithologic correlation between drill holes RDO-1 and N2, with data for N2 from MacLeod and Sammel (1982). Collar elevations are approximately 1,935 m for N2 and 1,969 m for RDO-1.

Waibel, 1983); these subdivisions are made on the basis of relative abundance of pumiceous and lithic material.

Of particular significance is the subdivision between 379.5 and 399.3 m, which contains the 158+° C water that induced artesian flow. Hydrothermally deposited minerals in this interval are as long as 4 mm in the largest dimension, and textures of intergrown minerals show abundant open spaces. The fact that these minerals had space to grow suggests (1) that this interval contains a large proportion of cobbles and boulders and/or (2) that the interval may have large, open fractures resulting in high secondary permeability.

HYDROTHERMAL ALTERATION

In RDO-1, there is virtually no hydrothermal alteration to a depth of 285 m. Local traces of deuteric minerals above 285 m consist of clear to white amorphous silica and thin greenish coatings of incipient clay minerals in vesicles. Present temperatures vary between 14.4° and 44.7° C from the surface to a depth of 285 m (Figure 4).

Hydrothermal alteration begins at 285 m and increases rapidly with depth; corresponding temperatures increase rapidly from 31° C at 275 m to 158° C at 350.5 m. Hydrothermal mineral distribution with depth is shown in Figure 4. The greatest proportion of the hydrothermal minerals (quartz, calcite, mordenite, chlorite, smectite, pyrite, and pyrrhotite) occur in open spaces such as vesicles, fractures, and pore spaces. Replacement of pumice matrix and mafic phenocrysts by smectite, chlorite, mordenite, quartz, and pyrite is locally pervasive.

The base of the basaltic tuff unit from 285 to 307.9 m contains trace amounts of smectite and pyrite as replacement minerals that may have formed from diagenetic processes and trace amounts of hydrothermally deposited siderite in small vesicles. Minor alteration in the basaltic sandstone, siltstone, and mudstone unit from 307.9 to 328.6 m consists of incipient replacement of basalt glass by smectite and local thin veinlets filled with calcite, aragonite, and rhodochrosite.

Alteration in the pumice and lithic tuff breccia unit from 328.6 to 424 m has resulted in replacement of glass in the pumiceous tuff groundmass and pumice fragments, and hydrothermal minerals have precipitated in open spaces. Volcanic lithic fragments were not permeable to hydrothermal fluids and, therefore, have only local alteration rims. Minor amounts of analcime fill pore spaces in the upper part of the unit. Pyrite, pyrrhotite, quartz, and either smectite or chlorite are concentrated from 328.6 to 379.5 m. The most intense hydrothermal alteration is in and adjacent to the interval from 379.5 to 397 m which contains the present hot-water (158+° C) aquifer. At approximately 386 m and extending down to approximately 414 m, large (4-mm) calcite blades have been deposited with quartz, mordenite, and chlorite in open spaces (Figures 5 and 6).

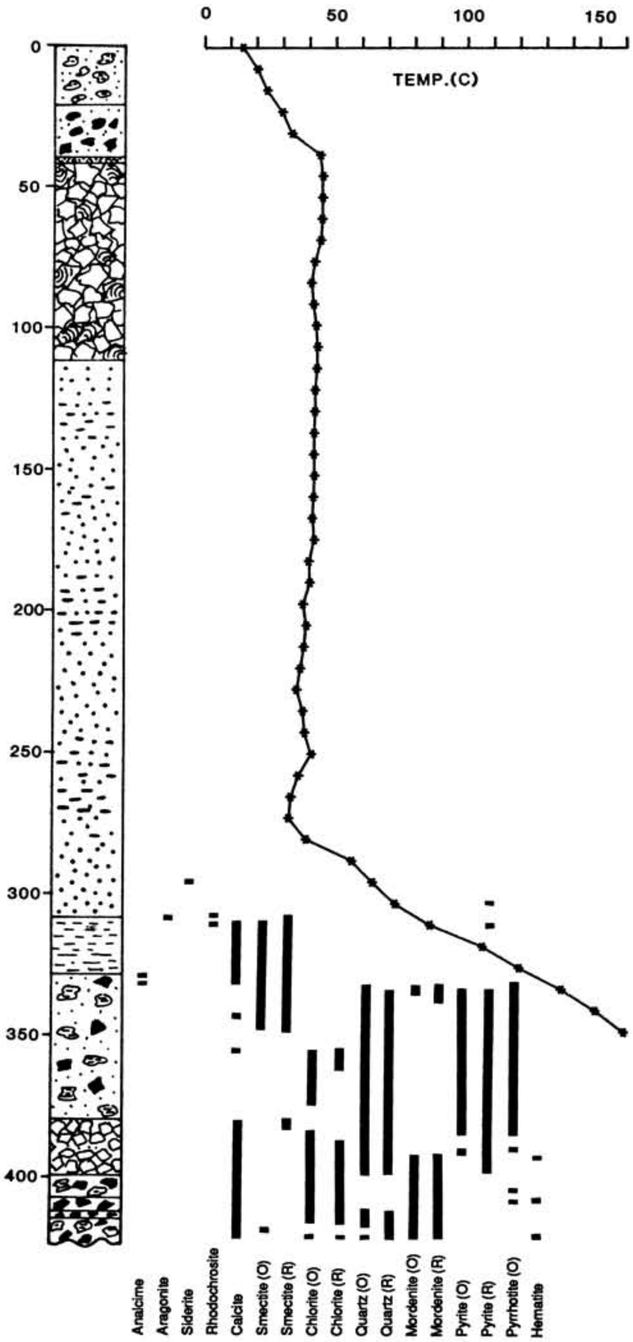


Figure 4. Lithology, hydrothermal mineral distribution, and measured temperatures plotted against depth for RDO-1. Lithologic symbols are as for Figures 2 and 3. No indications of relative abundances of minerals are shown. O = open-space deposit; R = replacement. Temperature data are from Black and others (1984).

In general, through the more highly altered part of RDO-1, the iron sulfides were deposited early, along with smectite. Pyrrhotite crystals are structurally hexagonal, as determined by X-ray diffraction techniques, and have not been altered or etched (Figure 7). The main sequence of deposition of the later minerals from first to last is pyrrhotite, mordenite, calcite, quartz, and chlorite; however, there is significant overlap of these phases, suggesting codeposition.

Most of the units of RDO-1 are quite permeable because of their primary lithologies; however, hydrothermal minerals have locally reduced permeability. The basaltic sandstone, siltstone, and mudstone unit would be expected to have lower primary permeability because of the fine-grained layers composing the unit. Reduction in permeability is caused principally by partial alteration of the glass particles to smectite, and this reaction, along with further reduction in permeability, can be expected to continue. Permeability of the pumiceous and lithic tuff breccia unit is greater where the proportion of lithic fragments to pumice fragments is greater and where the size of the fragments is larger. Pumice is more susceptible to hydrothermal alteration than are the volcanic lithic fragments. The present alteration is still in an early stage, and permeability is high through most of the unit. From 414.5 to 424 m, permeability has decreased because a high proportion of small pumice and tuff fragments have been extensively replaced, and vesicles have been filled by mordenite and chlorite. Quartz and calcite usually occur as euhedral crystals rather than massive vein or pore filling and, therefore, have less effect on overall rock permeability.

The effects of present temperatures on hydrothermal mineralogy can best be seen in the distribution of smectite and chlorite (Figure 4). Smectite occurs from 308 to 350 m at temperatures from approximately 80° to 150° C. Chlorite first appears at 355 m, where present temperatures are greater than 158° C. Isolated occurences of smectite are present at 380 and 417 m, where temperatures are probably higher than 158° C. There are no mixed-layer clays in RDO-1. Chlorite appears to be the clay mineral in equilibrium with the present waters below 355 m, and smectites either have not had time to react or have been shielded from the hydrothermal fluids by their location in small vesicles and in groundmass pore spaces.

Trace amounts of hematite that occur with chlorite below 393 m are more dependent upon local increases in oxygen fugacity than temperature.

COMPARISON OF RDO-1 AND N2

RDO-1 and N2 correlate well lithologically, as would be expected from their close proximity (Figure 3). The cores from N2 served as a guide for interpreting the cuttings from RDO-1. Intervals from the lower part of RDO-1 that could have been interpreted as lava flows were correlated with cores from N2 containing large volcanic lithic fragments.

Measured temperatures are consistently hotter in RDO-1 than at equivalent depths in N2 (Figures 4 and 8). The occurrence of hexagonal pyrrhotite in RDO-1 is suggestive of higher temper-

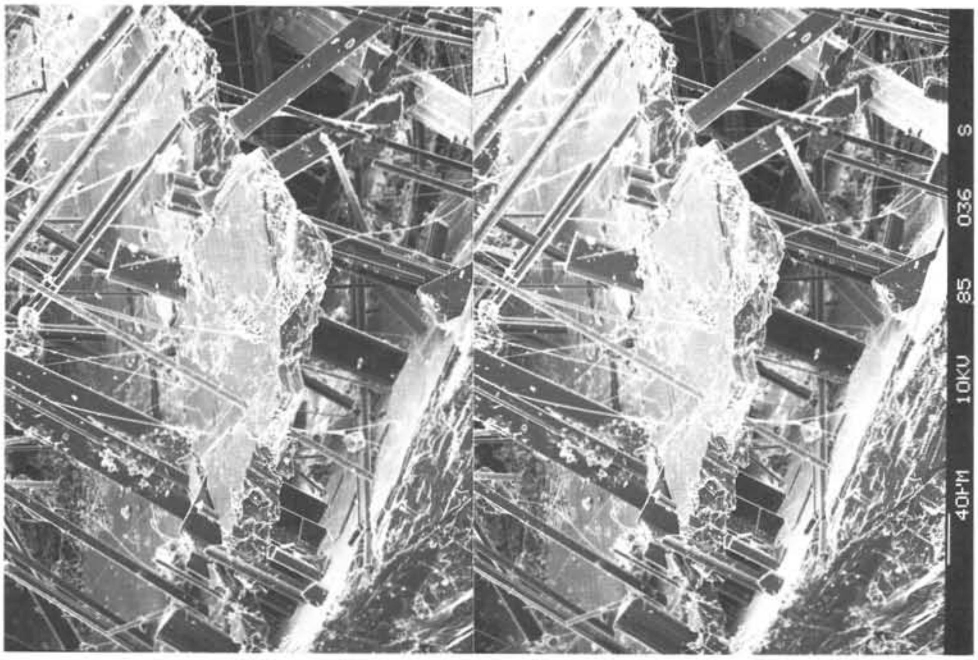


Figure 5. Scanning electron photomicrographs (stereo pair) showing bladed calcite and fibrous mordenite from a depth of 393 m.

atures than are found in the upper 500 m of N2, where pyrrhotite is monoclinic (Bargar and Keith, 1984). One bladed calcite sample from 390 m in RDO-1 was studied for oxygen and carbon isotopes for comparison with N2 carbonates. Assuming the same water occurs at this depth in both drill holes, calculated temperature of deposition of the bladed calcite is 220° C (Carothers and others, in preparation), which is higher than any measured temperature in RDO-1 but which corresponds to the temperature extrapolated by projecting the measured gradient to the aquifer depth by Black and others (1984) (Figure 4).

Rocks in both drill holes are virtually unaltered to approximately the 300-m depth; present temperatures between the surface and 300 m reach a maximum of about 40° C in N2 and 45° C in RDO-1. Incipient alteration in the basaltic sandstone, siltstone, and mudstone unit is similar in both holes where calcite and aragonite occur. Analcime in RDO-1 occurs very close to the same depth where analcime and other zeolites occur in N2 (Bargar and Keith, 1984). Only a trace of siderite is found in RDO-1, whereas it is abundant in N2; in both, it is a late mineral. The one occurence of rhodochrosite in RDO-1 appears to be codepositional with siderite; microprobe analyses of siderite crystals in N2 consistently show a large manganese component (Bargar and Keith, 1984). Calcite is the prominent carbonate in RDO-1, whereas siderite is prominent in the corresponding interval of N2.

In N2, a rhyodacite sill between 460 and 470 m interrupts the alteration mineralogy through a long interval of pumice and lithic tuff extending from 320 to 500 m (Figure 8). A higher temperature assemblage of quartz, calcite, chlorite, mordenite, pyrrhotite, and pyrite is superimposed upon a lower temperature assemblage of hydrated pumice glass and smectite assemblage between approximately 435 and 490 m. The intrusion of the rhyodacite sill could have caused the higher temperature mineral crystallization, or the fractures in the sill may have been sufficient to allow flow of thermal waters similar to that in RDO-1 at some time in the past. Later siderite, pyrite, and marcasite with locally developed native sulfur and iron hydroxide from oxidizing pyrrhotite occur in fractures in the massive rhyodacite sill, indicating that temperatures have decreased. Isotope data from N2 show that siderite was deposited at present measured temperatures, which range from 76° to 100° C (Carothers and others, in preparation). Present temperatures in the rhyodacite sill reach a maximum of 95° C, and the temperature maximum for the 320-to 500-m interval is 100° C at 415 m in the pumice and lithic tuff just above the sill. The rhyodacite sill is not penetrated in RDO-1, although stratigraphic correlation suggests that it might be present below total depth.

Alteration mineralogy in the pumice and lithic tuff breccia of RDO-1 samples below 328.6 m consists mainly of large, well-developed crystals of calcite, chlorite, quartz, and mordenite; in

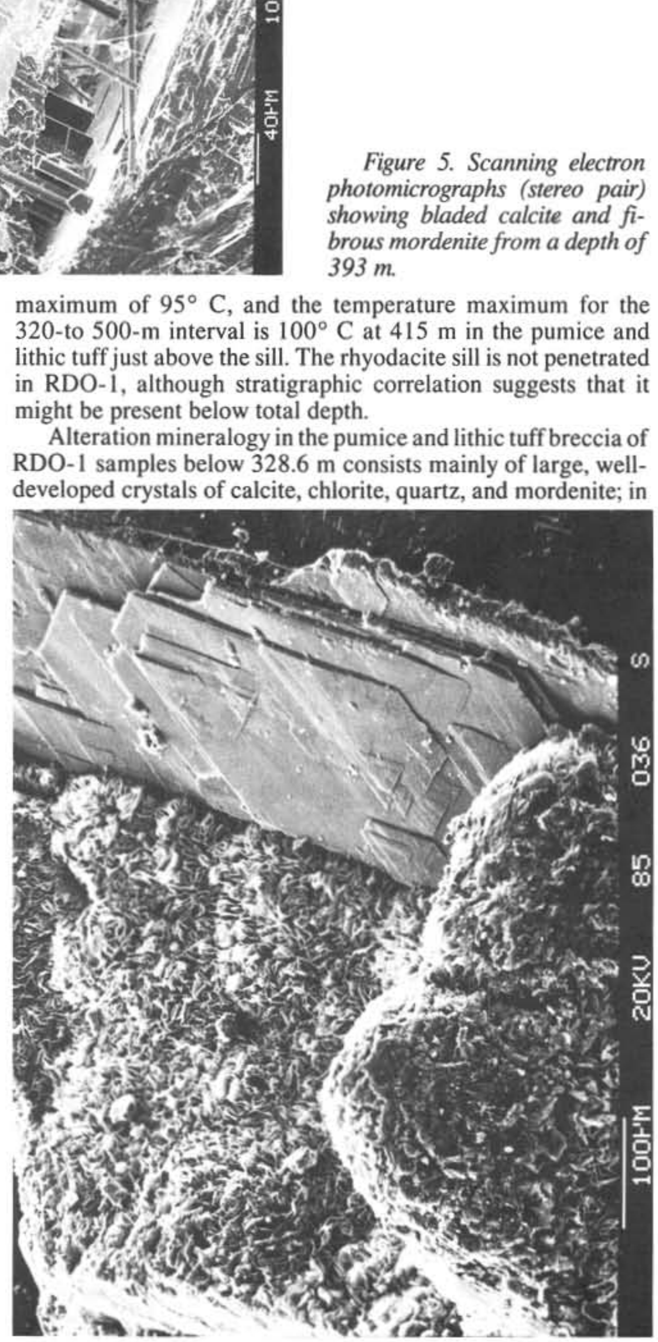


Figure 6. Scanning electron photomicrograph showing bladed calcite with chlorite from a depth of 390 m. 1 cm = 67 µm.

Figure 7. Scanning electron photomicrograph of twinned hexagonal pyrrhotite crystals from a depth of 335 m. 1 cm = 50 µm.

N2 adjacent to the rhyodacite sill, the same minerals occur, but they are fine grained. Large, hydrothermally deposited crystals in RDO-1 indicate open fractures or spaces between large lithic fragments, as opposed to small fractures and pore filling in N2.

The hot-water aquifer of RDO-1 is within the highly fractured or open-textured interval of the pumice and lithic tuff breccia between 379.5 and 397 m; in N2, the temperature bulge occurs in the same lithologic interval. The aquifer of RDO-1 projects parallel to stratigraphy to the temperature maximum of 100° C at 415 m in N2. Since the hydrothermal mineralogy at this level in N2 is incipient smectite replacement of pumice glass along with late siderite deposition in open spaces, temperatures at this level in N2 have not been higher than 100° C and probably have not been as hot as 100° C for a very long time (otherwise smectite alteration would be more extensive). A problem of cooling from at least 158° C in RDO-1 to 100° C in N2 over only 0.5 km horizontal distance suggests the path of the fluids may have been diverted from N2. Since the zone of the rhyodacite sill in N2 was once hotter than at present, either part of the N2 system may have been self sealed so that hot fluids no longer have access, or the total amount of hot fluids in the system has decreased so they are no longer reaching N2. The rhyodacite sill itself might now be a low-permeability layer providing a base for an aquifer in both drill holes. In any case, RDO-1 appears to be closer to a major upflow zone for thermal waters upflowing from a caldera ring fracture to the southeast (Figure 1) as suggested by Black and others (1984).

CONCLUSIONS

Lithologies can be correlated between RDO-1 and N2, and comparison of measured temperatures and hydrothermal alteration mineralogy show that RDO-1 is consistently hotter for given

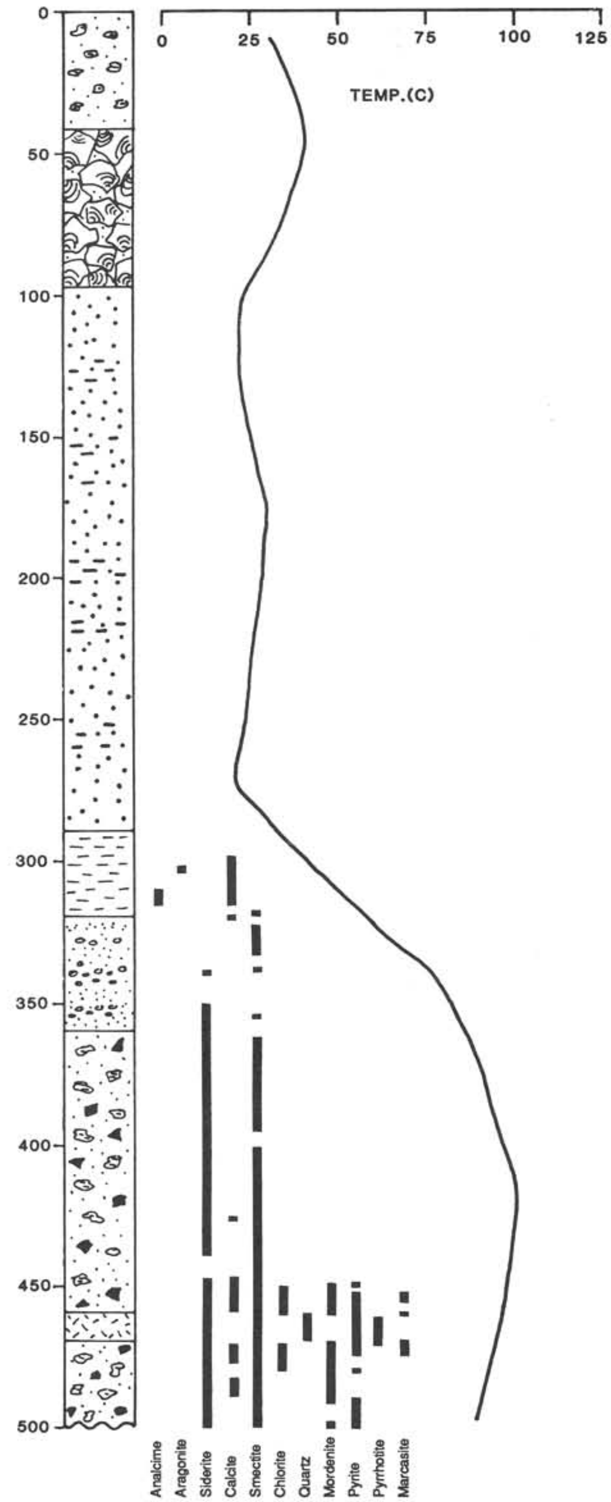


Figure 8. Lithology, hydrothermal mineral distribution, and temperatures measured during drilling plotted against depth for the upper 500 m of N2 (after Keith and others, 1984). Temperature data are from Sammel (1981). Lithologic symbols are as for Figure 3.

depths than N2. In RDO-1, the chlorite, calcite, quartz, and mordenite assemblage below approximately 355 m crystallized at temperatures at least as hot as the highest measured temperature of 158° C at 350.5 m. The minerals were probably deposited

*(Continued on page 110, **Newberry**)*

Eagle-Picher diatomite mine and processing plant, eastern Oregon

by R.C. Brittain, Exploration Manager, Minerals Division, Eagle-Picher Industries, Inc., P.O. Box 12130, Reno, Nevada 89510

INTRODUCTION

Eagle-Picher Industries, Inc., has commenced production of diatomaceous-earth filter aids at a processing plant located 7 mi west of Vale, Oregon. Crude ore is hauled to the plant from mine sites located northwest of Juntura in Harney and Malheur Counties.

The capital investment for the project was $13.5 million, with the major part of financing provided by Industrial Development Revenue Bonds.

COMPANY HISTORY

Eagle-Picher Industries, Inc., is a diversified manufacturer of industrial products with shares listed on the New York Stock Exchange. The company was started in 1843 and until the 1940's was principally a lead and zinc mining and smelting firm. It has since diversified into manufacturing and no longer is producing lead and zinc.

A partial list of products produced by the various divisions includes construction equipment, agricultural chemicals, concrete pipe, porcelain enamel frit, flexible packaging materials, diatomaceous earth products, tire molds, precision bearings, cleaning machinery, special-purpose batteries, molded automotive components, vibration-dampening assemblies, specialty-rubber-bonded parts, and high-speed printing services.

The company's first diatomite plant began production in 1946 at Clark, Nevada, and is still producing oil and grease absorbents and a variety of other products. In 1958, the company started production of filter aids at a plant located near Lovelock, Nevada, and subsequently expanded the capacity of that plant to meet the demands of a growing market.

Products from the Nevada plants and the new plant at Vale are all marketed worldwide under the trade name of Celatom, and this name was selected as a name for the rail siding at the Vale site.

DIATOMITE: WHAT IT IS AND HOW IT IS USED

Diatomite, or diatomaceous earth, is a sedimentary material that is formed by the accumulation of microscopic siliceous skeletons (frustules) of diatoms, which are single-celled aquatic plants related to algae that live in large numbers in bodies of water where suitable conditions exist.

The diatom skeletons are intricate structures with many submicron-sized pores and occur in a variety of sizes and shapes, with over 16,000 species having been identified.

Diatomite is normally white in color when exposed to oxidation and resembles chalk in color and texture. Because of a high ratio of voids to solids, it is light weight. When dry, a chunk of diatomite will float on water.

The chemical composition is amorphous silica, with impurities present in various amounts. Chemical impurities are primarily iron, calcium, aluminum, magnesium, and trace amounts of other elements. Physical impurities consisting of volcanic ash, clay minerals, and detrital material are common.

As an industrial mineral, diatomite has been used in a variety of ways, including filter aid, filler, absorbent, abrasive, anti-caking agent, insecticide carrier, catalyst support, and insulating material.

The most important use at the present time is for the production of filter aids that are used in the filtering of such liquids as corn syrup, beer, wine, raw sugar syrup, pharmaceuticals, edible oils, alginates, fruit and vegetable juices, dry-cleaning solvents, jet fuel, swimming pools, and municipal water.

Kadey (1983) has written an excellent article for the reader wishing more information on diatomite.

GEOLOGY

The diatomite deposits in the Juntura and Otis Basins are fossil diatomites that formed in fresh-water lakes during late Miocene and early Pliocene time. Because this was a period of intense volcanic activity, the lake waters had a high silica content, which was one of the required favorable conditions for the prolific diatom growth that developed and ultimately formed the deposits.

The bed rock underlying the sediments is an igneous complex of basalt flows and welded tuffs on which an irregular erosion surface developed prior to the deposition of the sediments. The deposits of economic interest are mostly under shallow overburden of gravel and soil. Erosion that followed extensive post-deposition faulting and uplift has removed any younger geologic units, such as the Drinkwater basalt and tuff members of the Drewsey Formation, that may have covered the diatomite at one time.

Beds of diatomite ranging in thickness from a few inches to 20 ft are separated by waste beds of volcanic ash, clay, or sandstone that are from a fraction of an inch to 10 ft thick. The dip of the beds is usually less than 15° but is locally steeper where disturbed by faulting or folding.

The thickness of the diatomite section is variable because of irregularity of the bed rock, varying conditions for diatom growth within the lakes, and post-deposition erosion. Thicknesses of 300 ft have been observed in drill holes in some localities.

The deposits of commercial-grade diatomite occur in several different locations on claims and leases covering 3,500 acres. Reserves are adequate for over 40 years of operation.

The diatomite is within the Juntura and Drewsey Formations as mapped and described by Gray (1956) and Shotwell and others (1963). These authors describe the geology and paleoecology of the Juntura Basin in detail.

MINING AND HAULING

The mining is by open-pit methods using rubber-tired scrapers and crawler bulldozers for the removal of overburden and stockpiling of ore.

The ore is mined and stockpiled at the mine site during the summer months and then hauled to the plant by trucks as required. The haulage distance is 70 mi from mine to plant.

The crude ore has a moisture content of 40 to 50 percent that may be reduced some during the mining process by planning the mining to take advantage of solar evaporation.

An emergency stockpile of ore will be maintained at Vines Hill, which is about 7 mi west of the plant, so that the plant will have a ready supply of ore available in case adverse weather makes the mine roads temporarily impassable to the haulage trucks.

Some unusable beds of clay, volcanic ash, and impure diatomite must be selectively removed and placed in landfill areas or stockpiles for later use in reclamation. Careful control of ore grade through frequent sampling and close supervision is required.

PROCESSING PLANT

At the plant, the crude ore is crushed in a hammer mill and stored in fine-ore storage bins. As it is fed into the milling process from the bins, it is milled to a very fine consistency and simultaneously dried in an air system that also removes impurities and unmilled diatomite with specially designed classification equipment.

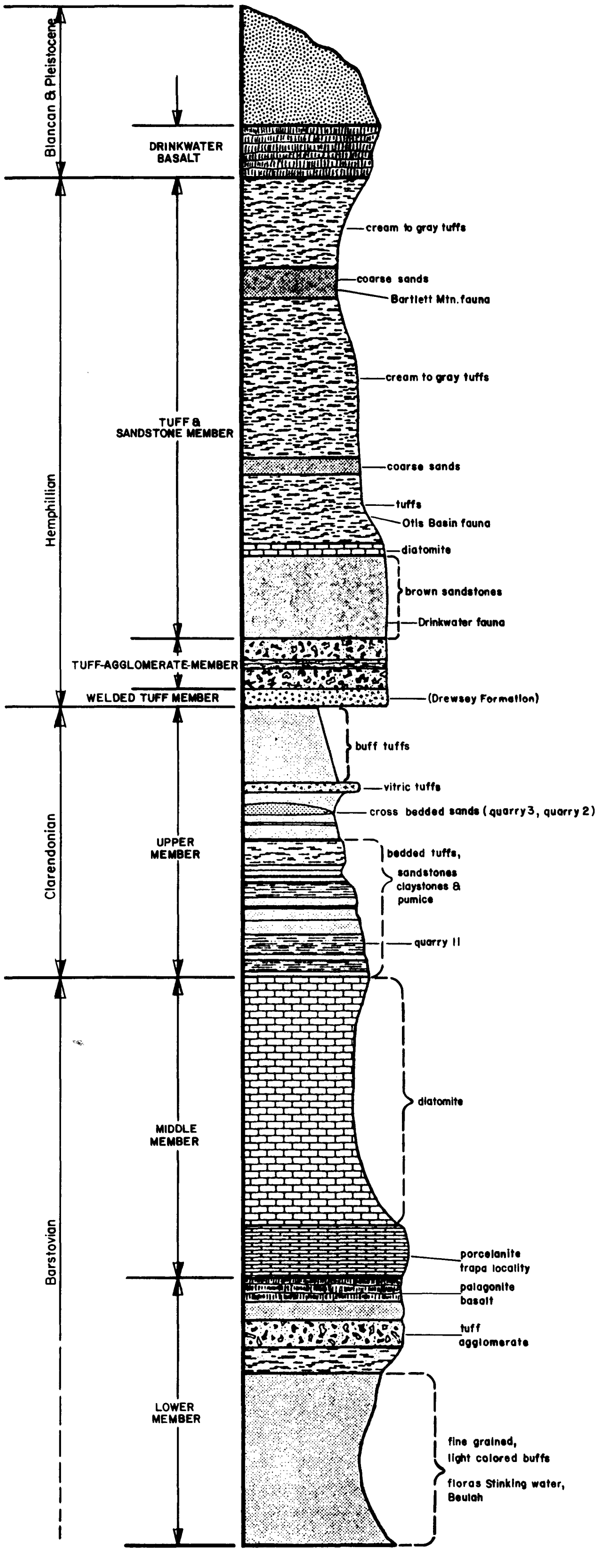
Soda ash is added to the cleaned diatomite as a fluxing agent, and the mixture is heated to incipient fusion in a rotary kiln at temperatures of 1,600° to 1,900° F.

After being discharged from the kiln, the diatomite is in soft lumps and must be milled again. It is then classified in an air system to control particle size and filtration properties in the various grades of filter aids that are produced.

The finished products are packaged in bags for shipment or may be loaded directly into rail cars or trucks in bulk form.

Waste materials removed from the diatomite are hauled back to the mine site for disposal in planned landfill sites or use in reclamation.

The plant is equipped with baghouses to remove dust particles from air that is discharged to the atmosphere and is designed to meet or exceed Oregon Department of Environmental Quality standards for air and water pollution.



Geological sections of the Juntura and Drewsey Formations. Modified from Shotwell and others (1963). Vertical scale: 1 inch = 300 feet.

RECLAMATION

The mining operation will comply with reclamation standards imposed by the Bureau of Land Management and the State of Oregon.

As planned, when mining begins in an area, all topsoil is carefully removed and saved in a stockpile area for later use in recovering mined-out areas and waste dump areas. Mined-out areas and waste dumps will be graded prior to covering with the topsoil. The areas then will be seeded with seed mixtures that have been determined to be beneficial in preventing erosion and that will provide forage for livestock and game animals. The best seed mixtures will be determined by planting test plots.

During mining, water samples will be taken from drainages in the area to monitor whether or not there is an increase in sediment or pollutants that might have an adverse effect on fisheries or downstream users of the water.

IMPACT ON AREA

The project will have a favorable effect in the area by helping diversify the local economy and by creating 30 to 35 new jobs. Four people have been transferred from other operations to manage the plant and mine. The balance of the work force has been hired locally.

The crew for the mining and crude-ore hauling is supplied by local contractors who have contracted to do this work. These activities will provide about six full-time jobs and seven seasonal jobs.

As a result of the plant construction, Cascade Natural Gas has built a natural-gas pipeline to serve both the plant and the Vale community.

Vale will receive the proceeds of a $675,000 Urban Development Action Grant loan to use for community improvements or to attract other industries.

The plant and mine are designed to be nonpolluting and will not have a significant adverse impact on the environment.

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Rapidly surging Alaska glacier seals off fiord and creates new lake

A "world class" natural event has begun in Alaska — the rapid surging of Hubbard Glacier that has sealed off Russell Fiord and could eventually fill Disenchantment Bay and Yakutat Bay with ice, according to a U.S. Geological Survey (USGS) scientist. "This event is probably the largest natural alteration in ocean, glaciers, lakes, and rivers to occur in North America within our lifetimes," Larry Mayo, a USGS glaciologist in Fairbanks, Alaska, said recently.

Mayo said measurements show that Valerie Glacier, a main tributary to Hubbard Glacier, is moving at rates of up to 130 ft per day at a point about 6 mi upstream from the end of Hubbard, although no measurements of movement have been made at the terminus. Ice calving at the terminus of Hubbard removes about 50 ft per day off the end of the glacier. The USGS scientist emphasized that, based on the geologic and hydrologic history of Hubbard Glacier, the process now going on "is not a temporary situation but is part of perhaps a thousand-year cycle that encompasses major changes in the hydrology of a large and compex system." The glacier has been in an advancing stage since 1900 but began surging forward rapidly during the winter of 1985-86.

The rising water level in Russell Fiord behind the dam formed by the glacier eventually could cause the water to overflow the dam, resulting in a sudden "outburst flood" that could wash away part of the dam and quickly lower the water level in the fiord, which is now being called Russell Lake. The entrance to the fiord was off Disenchantment Bay, which forms a narrow inner arm off the larger Yakutat Bay.

Hubbard and Valerie Glaciers are in the Wrangell St. Elias National Park, but Hubbard Glacier is surging into the Russell Fiord Wilderness Area in the Tongass National Forest. Mayo said the community of Yakutat on the Pacific Ocean coast at the mouth of Yakutat Bay would not be endangered, but saltwater fish and wildlife trapped in Russell Lake probably are doomed as the oxygen in the lake water becomes depleted.

Mayo said Hubbard is only one of about 20 glaciers that are presently surging in the area where the southeastern Alaska Panhandle connects with the main part of the state, but it is having the most dramatic effects. He said scientists don't fully understand why these glaciers are suddenly moving forward rapidly, while others in the area are not surging.

The exact reasons why glaciers surge or retreat are little understood, Mayo said, but scientists are working to solve the mystery. He said one thing being looked at is the possibility that surges are triggered by unusually deep snowpacks on the tops of glaciers.

Mayo said studies of the geologic and hydrologic history of Hubbard indicate that, during cycles of about a thousand years or longer, the glacier alternately retreats and advances. About 800 years ago, the glacier extended all the way to the sea at the mouth of Yakutat Bay and filled both Disenchantment Bay and Yakutat Bay, and there is no reason to believe that the glacier, during its current cycle, won't do the same thing within several hundred years.

Mayo said Hubbard Glacier's advance and its closing of Russell Fiord offer unprecedented opportunities for scientists to study its relationship to climate, oceans, rivers, lakes, fish and sea mammals, timber, engineering works, and people, as well as hydrology and geology. The enlarging glacier will gradually alter climate locally in the region. There are also indications that residual salt in Russell Lake may enter the local ground-water system and affect the water quality of small streams in the area.

— USGS press release

GSA announces leaders for centennial meeting in 1988

The Geological Society of America (GSA) will celebrate its 100th annual meeting, October 31 to November 3, 1988, in Denver with a special array of programs. The society recently announced the names of persons who will be chairing or coordinating the various parts of the celebration meeting.

William W. Hay, A.R. "Pete" Palmer, and Samuel S. Adams will coordinate the vast technical program for the meeting of over 6,000 earth scientists. Field trips, which will focus on classic geology or geologic problems about which our understanding has changed over the past 100 years, will be organized by Harry A. Tourtelot and Omer B. Raup. The science theater program will be led by U.S. Geological Survey geologist Kathleen M. Johnson and the transportation program by Charles F. Kluth. Technical Services Chairman William W. Atkinson, Jr., will coordinate audio-visual needs and student involvement for the meeting; Ester R. Magathan will coordinate special events and Jackie Meisner and Barbara Curtis the guest program.

—GSA news release

(Newberry, continued from page 107)

in the present hydrothermal regime. A similar mineral assemblage between 448 and 485 m in N2 is associated with a rhyodacite sill, showing that higher temperatures once existed in this part of N2.

The hot-water aquifer between 379.5 and 397 m in RDO-1 correlates with the 100° C temperature maximum at 415 m in N2. The temperature change from 158+° C to 100° C in the aquifer between the two drill holes over a distance of half a kilometer indicates that the water may not flow directly between them. Either the water has cooled in a very short distance, or it has been diverted from N2.

This study supports the conclusions of Sammel (1981, 1983) and Black and others (1984) that, relative to N2, RDO-1 is closer to a caldera ring fracture system shown by MacLeod and others (1982), where upflowing thermal waters are apparently moving upward along the ring fracture system and then spreading laterally through permeable layers within the caldera.

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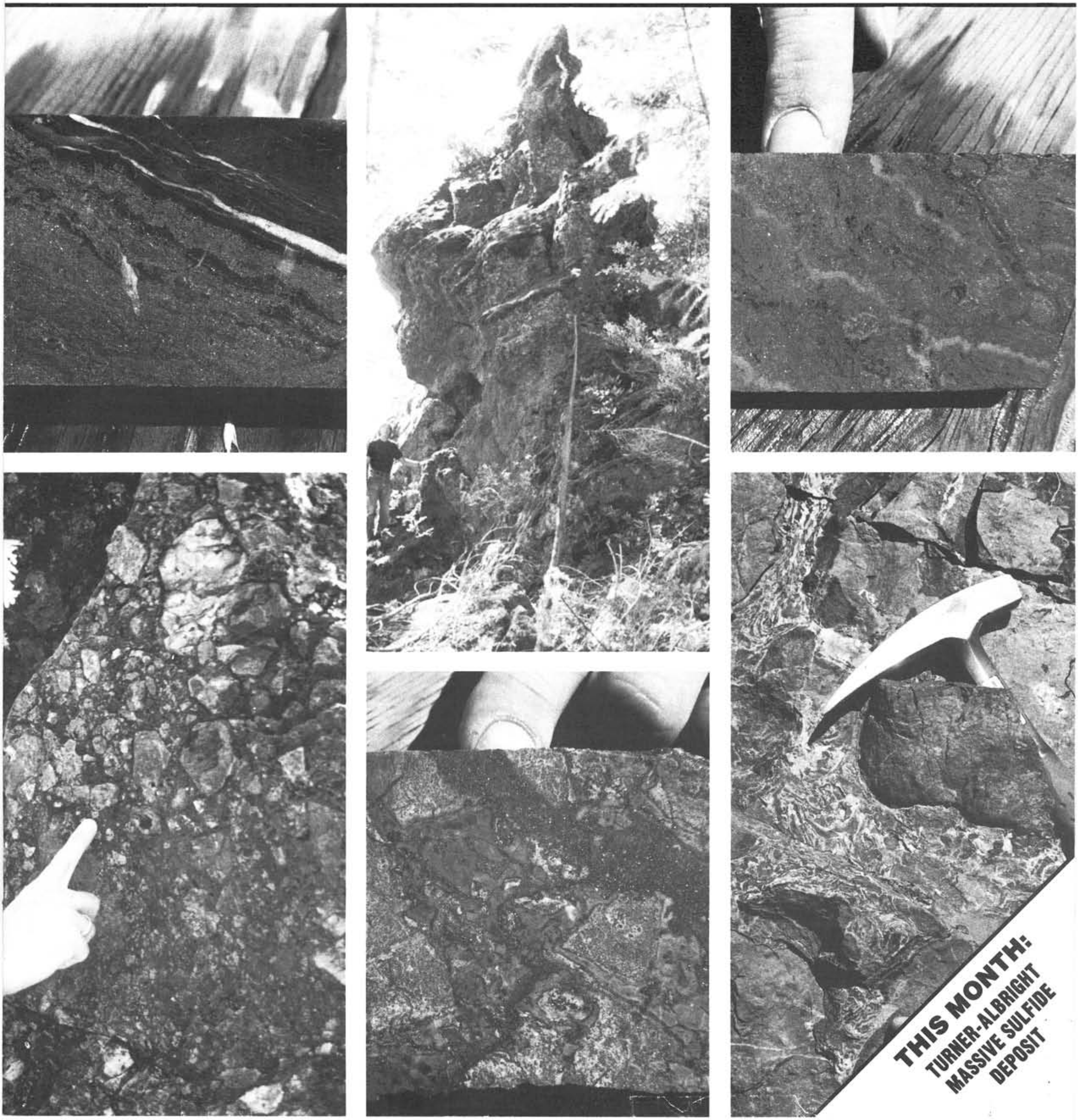

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The style to be followed is generally that of U.S. Geological Survey publications (see the USGS manual *Suggestions to Authors,* 6th ed., 1978). The bibliography should be limited to "References Cited." Authors are responsible for the accuracy of the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

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

COVER PHOTO

Details from Turner-Albright massive sulfide deposit discussed in article beginning on next page. Clockwise from upper left: Cut drill core from stratigraphic top of Main Upper Zone (p. 120), showing contact between massive colloform banded pyrite/sphalerite and finely laminated black (carbonaceous) mudstone. — Large "llozzan" outcrop associated with South Zone gossans (p. 117 and 120, footnote). — Cut drill core showing massive sphalerite replacement of basalt within basin-floor rubble (p. 119). — Hyalcoclastite breccia between basalt pillows (p. 117). — Cut drill core from basin-floor rubble showing hydrothermally altered basalt and silicification and pyritization of matrix. — Fragmental and brecciated textures associated with "llozzan" (above), including partially silicified and pyritized basalt and completely silicified basaltic glass.

OIL AND GAS NEWS

ARCO successful at Mist

ARCO Oil and Gas Company drilled the well Columbia County 14-23 to a total depth of 2,180 ft and has completed it as a producer from the Clark and Wilson sandstone at a rate of 3.2 MMcfd. ARCO next drilled the Longview Fibre 41-35 to a total depth of 1,585 ft. This well has also been completed as a producer, but the flow rate has not yet been released. The third well drilled this summer was the Cavenham Forest Industries 33-9. This well was drilled to a total depth of 3,242 ft and was plugged and abandoned. ARCO next plans to drill the Cavenham Forest Industries 41-4. This well is permitted as a 2,400-ft test.

Exploratory well planned for Marion County

Damon Petroleum Corp., located in Woodburn, will drill its Stauffer Farms 35-1 this fall. The well is to be located in sec. 35, T. 4 S., R. 1 W., near the city of Hubbard. The well has a proposed depth of 2,800 ft.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
376	ARCO Col. Co. 42-8-54 009-00213	NE¼ sec. 8 T. 5 N., R. 4 W. Columbia County	Application; 2,750.

□

Mineral industry costs to be studied

With today's unpredictable mineral markets, it is more critical than ever before to accurately predict production costs. Both new and existing operations are saddled with small profit margins and highly variable product prices.

To help mineral producers understand costs, the Northwest Mining Association will hold its 'Mineral Industry Cost" short course on Dec. 1, 2, and 3, 1986, at the Sheraton Hotel in Spokane, Washington.

Jack Hoskins, head of the metallurgy and Mining Department of the College of Mines, University of Idaho, will serve as course director. "The problems of accurate cost estimating and control continue to be foremost in the minds of property developers and operators," Hoskins says.

Otto L. Schumacher, president of Mining Cost Service in Spokane, will act as co-director. "Although mineral industry costs have been the topics of short courses in 1976 and 1980, the drastic changes in our industry and in metal markets make a new review essential," Schumacher says.

Hoskins and Schumacher have assembled nineteen industry and academic experts to provide practical and up-to-the-minute information on the costs of exploration, development, operating, marketing, and environmental control for existing and proposed operations. The short course will be a series of working sessions, not lectures. Financial systems and control, labor costs and productivity, environmental permitting, comparison of costs of mining methods, processing costs including leaching of gold, and case studies of cost estimating will be studied.

The course, along with the Association's second short course, "Industrial Minerals — Are They for You?" will immediately precede the Northwest Mining Association's 92nd Annual Convention, which will be held in Spokane on Dec. 4, 5, and 6, 1986. College credit will be available. Enrollment will be limited to 200. To register or for more information, contact the Northwest Mining Association, (509) 624-1158.

— *Northwest Mining Association news release*

Geologic setting of the Turner-Albright massive sulfide deposit, Josephine County, Oregon

by Michael D. Strickler, Geologist, Litho-Logic Resources, 207-A SW "G" Street, Grants Pass, OR 97526

INTRODUCTION

Several small- to medium-sized volcanogenic massive sulfide deposits have been identified within ophiolitic volcanic rocks of Josephine County, Oregon. The most notable occurrence located to date is the Turner-Albright deposit (Figure 1, Plate 1), which was formed by a combination of sub-seafloor replacement and seafloor exhalative (venting) processes within a back-arc rifting environment. As currently defined, the Turner-Albright contains minimum drill-indicated reserves of 6.5 million tons of massive and semimassive sulfides. Values are reported for gold, silver, copper, zinc, and cobalt, with 2 to 4 million tons being potentially economic at current metal prices. Geological and geophysical data suggest that the deposit may be significantly larger and that the present reserves may be substantially increased by additional exploration adjacent to the known mineralization. This brief discussion is intended to summarize the geologic setting and history of the Turner-Albright and to relate some of the factors that may affect a future production decision.

REGIONAL GEOLOGIC SETTING

The regional geology of southwestern Oregon and northwestern California has been the subject of numerous studies, especially in recent years (Cater and Wells, 1953; Wells and Walker, 1953; Helming, 1966; Garcia, 1976, 1979; Vail, 1977; Cunningham, 1979; Ramp and Peterson, 1979; Harper, 1980, 1983; and others). Pioneer workers, including Diller (1914), Winchell (1914), and Shenon (1933a,b), mapped the many mines and prospects that were being actively worked in the region in the early 1900's.

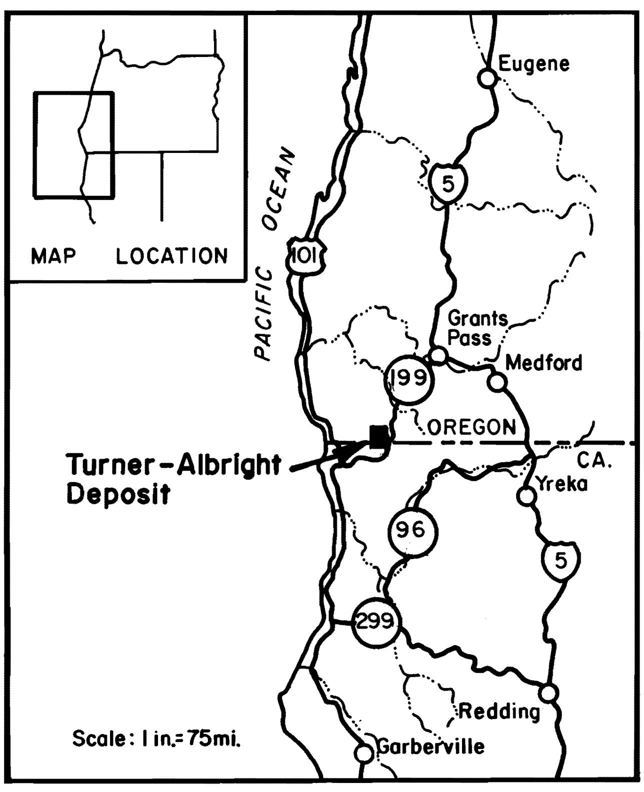


Figure 1. Map showing the location of the Turner-Albright massive sulfide deposit.

The Turner-Albright deposit occurs in the Western Jurassic Belt (WJB), the westernmost and youngest of four arcuate, north-south-trending lithotectonic belts that comprise the Klamath Mountains geomorphic province. The lithologies and age relationships within the Klamaths indicate repeated accretion, beginning in the early to middle Paleozoic and continuing through the Mesozoic, of ophiolitic and/or island-arc terrains and associated sedimentary units to the western edge of the North American continent. Jurassic and Cretaceous intrusives (gabbroic to granitic) intrude all the units. The WJB is in thrust contact with a similar suite of upper Paleozoic and Triassic ophiolitic/arc units to the east and is underthrust from the west by the upper Jurassic to Cretaceous Francisan (Dothan) melange.

Prominent features of the WJB in southwestern Oregon and northwestern California are the Josephine Ophiolite (Figure 2) and coeval volcaniclastics and flows associated with island-arc development. The Josephine Ophiolite, dated at 157 million years (m.y.) (Harper and Saleeby, 1980), is interpreted to be the product of Jurassic back-arc spreading, with island-arc development occurring relatively westward. The ophiolite sequence, which regionally trends north-northeast with a steep southeast dip, is essentially complete, with preservation of all major lithologies associated with classic ophiolite stratigraphy. The basal ultramafic portion (Josephine Peridotite) is comprised predominantly of tectonized harzburgite that has undergone partial to locally complete serpentinization. Cumulate and massive gabbro is well exposed approximately 2.5 mi southwest of the Turner-Albright in the headwaters of the Monkey Creek drainage. The entire sheeted dike complex, from the lower transition with the gabbro to the upper gradational contact with extrusive volcanic flows and pillows, is preserved essentially intact on both flanks of Monkey Creek Ridge.

In southwestern Oregon, Jurassic extrusive rocks (both ophiolitic and arc-derived) have been collectively named the Rogue Volcanics and include basic to locally felsic flows, tuffs, breccias, and agglomerates. Volcanic members associated with the Josephine Ophiolite include basaltic flows and pillows with interlayered breccias, hyaloclastites, and relatively thin clastic and/or chemical sedimentary horizons. The Josephine Ophiolite, as well as the associated island-arc volcanic rocks, are conformably overlain by the Galice Formation, which is composed predomi-

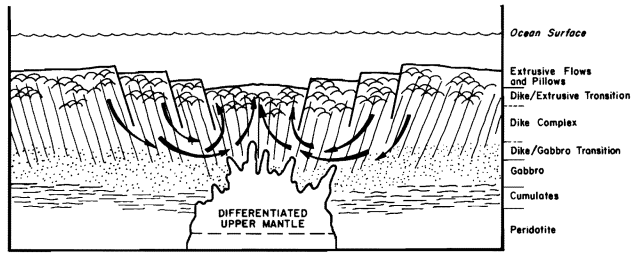


Figure 2. Schematic diagram showing the gross stratigraphy of the Josephine Ophiolite and the relative positions of the various units that occur in ophiolite suites. The Turner-Albright deposit is located immediately above the base of the extrusive flows and pillows.

nantly of interbedded graywacke and shale. Type localities for the Rogue and Galice Formations occur northwest of Grants Pass in the Galice District and as such are associated with island-arc development. Harper (1983) has proposed that the WJB be divided into two terrains: a northern Rogue River terrain, which would include the intermediate to locally felsic island-arc volcaniclastic rocks and flows typical of the Galice District, and a southern Josephine terrain, represented by the mafic and ultramafic units of the Josephine Ophiolite.

Precious- and base-metal mineralization within the WJB is widespread and consists of several varied genetic types. In addition to the Turner-Albright, several other massive sulfide deposits have been located. While a lack of data prohibits a definitive genetic classification for most of the showings, it is probable that several may be associated with ophiolite development (e.g., Monumental, Fall Creek, Eagle Group), while others appear to be related to island-arc development (e.g., Almeda, Goff, Silver Peak, Yankee Silver Lode). Numerous very high-grade gold/silver/copper/zinc occurrences commonly associated with mafic to granitic intrusives occur throughout the Klamath Mountains. Both vein and high-grade gold "pockets" have eroded to form locally rich placer deposits, many of which have been extensively worked by methods ranging from pick-and-shovel to large-scale hydraulic mining.

TURNER-ALBRIGHT DEPOSIT

Geographic setting

The Turner-Albright deposit is situated in southern Josephine County, immediately north of the California border and approximately 2 mi west of Highway 199 (Figure 1). Access to the Turner-Albright is via Lone Mountain Road in O'Brien, Oregon, which parallels the West Fork of the Illinois River to the turnoff to the property, a distance of approximately 6 mi. From the turnoff, an extensive system of access and drill roads provide year-round entry to most portions of the deposit.

Relief at the Turner-Albright is moderate to locally steep, with elevations ranging from 2,000 to 3,100 ft. Area rainfall during the winter months is quite heavy, with seasonal averages in excess of 100 in. to be expected. Snowfall is common above 3,000 ft and can last from December through April. Storms come in groups, with weeks of clear weather common between systems. Summers are hot and dry, with highs above 100° F not uncommon from July through mid-September. Steep slopes covered with thick stands of brush and timber, old-growth poison oak, and yellow jackets with a special vengeance for geologists all tend to hinder field activities during the summer months.

Property history

Mineralization associated with the Turner-Albright deposit

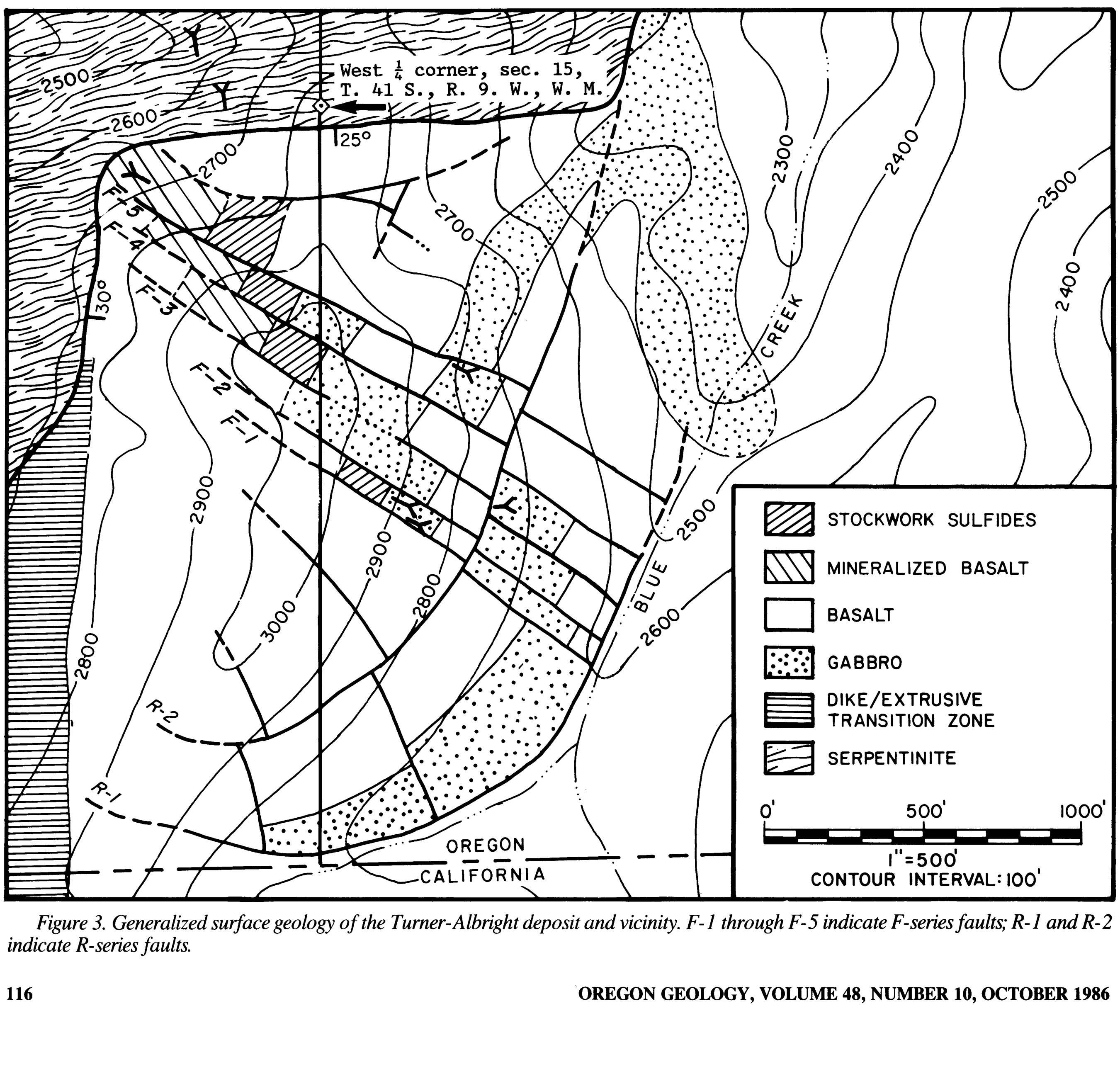


Figure 3. Generalized surface geology of the Turner-Albright deposit and vicinity. F-1 through F-5 indicate F-series faults; R-1 and R-2 indicate R-series faults.

was originally located in the late 1800's. Early efforts concentrated on developing the potential gold content of several discontinuous gossan outcrops located on or near the ridge separating Blue Creek from the headwaters of the West Fork of the Illinois River. Sporadic exploration and limited development continued through the 1930's, but these efforts were not successful in defining an economic reserve. Several short crosscuts driven at the base of the oxide horizon reached primary sulfides that were of sufficient grade to allow three claims to be patented in the late 1950's.

Exploration of the underlying sulfide deposit began in earnest in 1954 with a one-year program by Granby International. Associated Geologists of Grants Pass continued exploration below the gossans intermittently throughout the 1960's and early 1970's with several programs consisting of churn and shallow diamond core drilling. A two-year program by American Selco in 1974-1975 explored the potential of the southernmost (South Zone) gossans and resulted in drill-indicated reserves of 150,000 tons of sulfide ore averaging 1.70 percent copper and 0.03 oz/ton of gold across an 8-ft-wide zone of highly siliceous basaltic breccias. Evidence of a large mineralized body north of the South Zone was indicated by an induced polarization geophysical survey and three short diamond drill holes; however, American Selco considered the prospects of locating an economic deposit poor and allowed its option to expire at the end of 1975.

Baretta Mines, Ltd., of Calgary, Alberta, Canada, obtained an option upon termination of the American Selco program. Through August 1981, Baretta Mining, Inc., a wholly-owned subsidiary, conducted extensive exploration on the Turner-Albright itself, as well as initial exploration of favorable units to the south and southwest. A total of 30 diamond core holes, with an aggregate length of 35,500 ft, were completed at the Turner-Albright, resulting in an indicated in-place geologic reserve of 3 million tons averaging 0.09 oz/ton of gold, with additional values in copper, zinc, silver, and cobalt. Drilling by Noranda Exploration in 1982 and Rayrock Mines, Inc., in 1983-1984 continued to refine both the geologic and structural characteristics of the deposit. Drilling on the deposit to date exceeds 75,000 ft in 80 separate drill holes. At the present time, reserve estimates place the Turner-Albright at 2 to 4 million tons averaging approximately 0.12 oz/ton of gold, 0.60 oz/ton of silver, 1.55 percent copper, 3.70 percent zinc, and 0.50 percent cobalt. The wide range in tonnage reflects the current uncertainty over the full effect that post-mineralization faulting may have had on the continuity of portions of the deposit.

Recently, two separate studies of the Turner-Albright have been initiated by branches of the Federal Government to study the genetic and metallurgical characteristics of the deposit. A team of geologists, marine geologists, and geochemists from the U.S. Geological Survey (USGS) are studying the Turner-Albright to determine its similarities to active hydrothermal systems that have recently been identified at several venting sites along mid-ocean ridges. In addition, the U.S. Bureau of Mines is beginning a detailed mineralogical study of the cobalt-bearing sulfides at the Turner-Albright. Their intent is to help in defining and developing a metallurgical process to treat the complex ores found at the deposit.

Lithology

The Turner-Albright deposit is situated near the base of the extrusive pillow lavas and flows of the Josephine Ophiolite, 50-200 m above their gradational lower contact with the sheeted dike sequence. In the immediate vicinity of the Turner-Albright, the majority of ophiolite-related lithologies normally found stratigraphically below the extrusives are missing due to post-ophiolitic low-angle faulting that has juxtaposed the uppermost portion of the sheeted dike/extrusive rock transition zone and serpentinized mantle peridotite. In comparison with the total section as exposed south of the Turner-Albright, up to 1.5 km or more of the ophiolite stratigraphy is missing, including the middle and lower sheeted dikes, the entire massive and cumulate gabbro sequence, and an unknown amount of mantle peridotite.

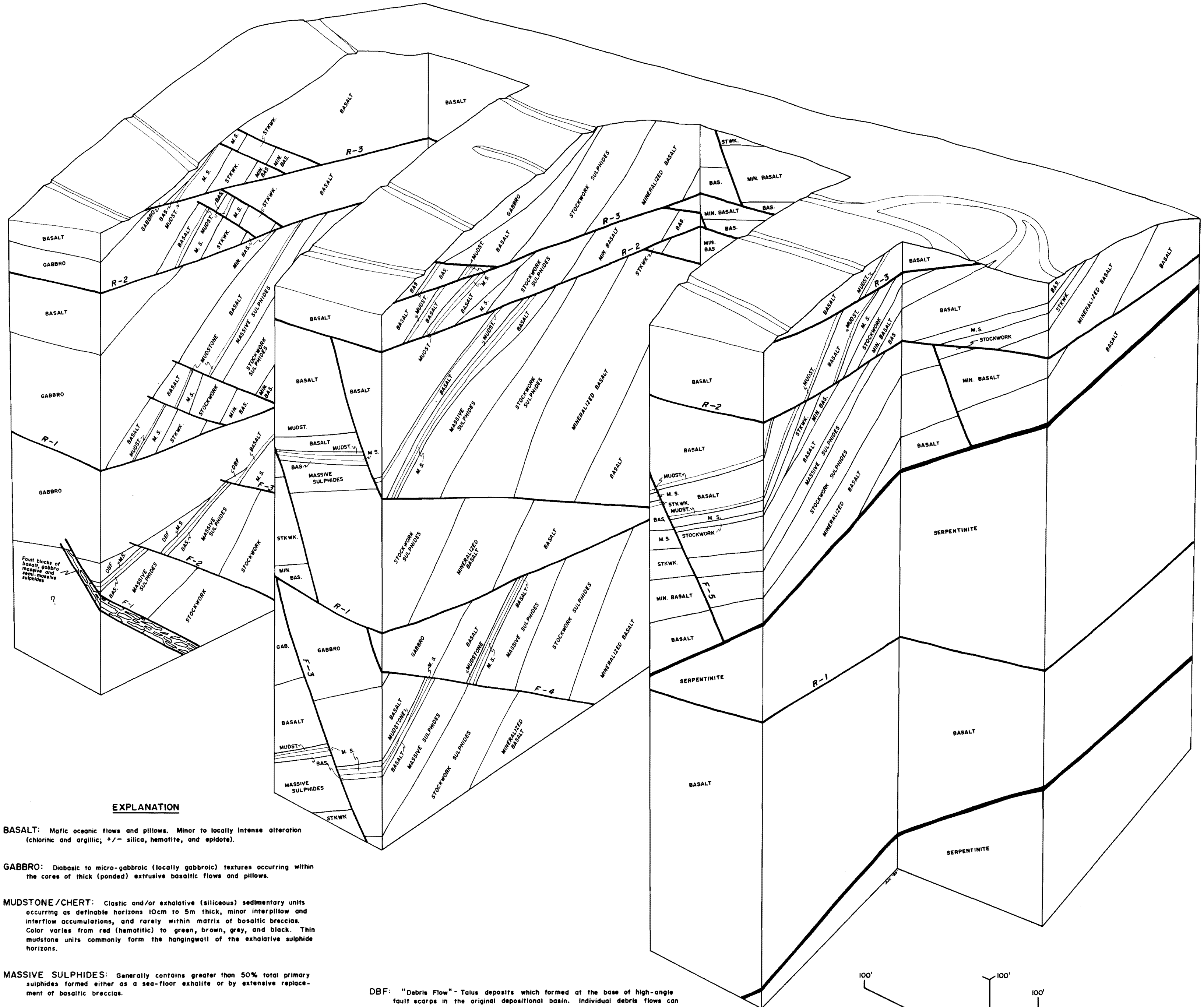
With the exception of numerous mafic pegmatite and rodingite dikes that occur within major shears in the ultramafic mass, all of the lithologies currently exposed at the Turner-Albright are interpreted to be associated with the primary development of the Josephine Ophiolite (Figure 3). Following is a brief description of the major units identified at the Turner-Albright deposit.

Basalt: Extrusive volcanic rocks occurring at the Turner-Albright consist of basaltic flows, pillows, and hyaloclastites that commonly contain plagioclase, clinopyroxene, and/or iron titanium phenocrysts. Feldspar microlites and/or calcite veinlets and amygdules occur locally, and individual units may be locally vesicular. Well-developed pillow structures are evident, both in outcrop and in drill core. Minor to locally intense alteration occurs, consisting of prehnite/pumpellyite, chlorite, sphene, and albite (±silica, hematite, and epidote), with increased alteration being localized within and adjacent to zones of shearing and faulting. Except where associated with mineralization, clinopyroxene is rarely altered to any degree. Regional prehnite/pumpellyite-facies metamorphism has overprinted much of the original alteration associated with seafloor and hydrothermal reactions, and it is often difficult to determine the age or origin of specific alteration products.

Recent work by Robert Zierenberg of the USGS has defined a second extrusive unit that is of limited extent and apparently restricted to the mineralized horizons. To date, this unit, which consists of glassy fragments of a relatively primitive mafic magma, has not been found as flows or pillows. The rock typically exhibits phenocrysts of olivine and/or chromium spinel (with occasional plagioclase) in a groundmass of glass and radiating clusters of quenched pyroxene crystals. Extensive hydrothermal alteration within the mineralized horizon commonly masks the nature of many of the fragments; however, where primary textures are still visible, clasts of the regionally dominant plagioclase-bearing lava series appear to be restricted to the lowest portions of the mineralized horizons and may represent minor accumulations of rubble on the seafloor prior to the extrusion of the mafic lavas.

Gabbro (coarse-grained basalt): As applied at the Turner-Albright, the term "gabbro" refers to diabasic to microgabbroic (locally gabbroic) textures that occur within the cores of thick extrusive basalt flows and/or pillows. These units commonly contain plagioclase and/or pyroxene phenocrysts up to 5 mm long in a generally fine-grained to aphanitic groundmass. To date, there is no compelling evidence to indicate an intrusive origin for the unit, and the gabbro is interpreted to represent coarse-grained members of the dominant plagioclase-bearing lava series. Thick sections (>50 m) of gabbroic-textured flows commonly occur within 10 m of the top of the mineralized horizons and may represent ponding of basaltic lavas within the primary depositional basin.

Mudstone: Very fine-grained clastic sedimentary units occur as definable horizons 10 cm to 5 m thick, as minor interpillow and interflow accumulations, and within the matrix of hyaloclastite breccias. Color varies from red (hematitic) to green, brown, gray, and black (carbonaceous). Green and gray mudstones are often indistinguishable from silicified basaltic gouge in drill core. Measurements of bedding from outcrop, as well as subsurface structural calculations from three points, indicate a regular north-northeast strike to the units (subparallel to the regional trend of the ophiolite); however, dips vary from 30° SE. to nearly vertical. Composition of individual clasts is difficult to deter-



EXPLANATION

BASALT: Mafic oceanic flows and pillows. Minor to locally intense alteration (chloritic and argillic; +/− silica, hematite, and epidote).

GABBRO: Diabasic to micro-gabbroic (locally gabbroic) textures occurring within the cores of thick (ponded) extrusive basaltic flows and pillows.

MUDSTONE/CHERT: Clastic and/or exhalative (siliceous) sedimentary units occurring as definable horizons 10cm to 5m thick, minor interpillow and interflow accumulations, and rarely within matrix of basaltic breccias. Color varies from red (hematitic) to green, brown, grey, and black. Thin mudstone units commonly form the hangingwall of the exhalative sulphide horizons.

MASSIVE SULPHIDES: Generally contains greater than 50% total primary sulphides formed either as a sea-floor exhalite or by extensive replacement of basaltic breccias.

STOCKWORK SULPHIDES: Forms the "silica-stockwork" feeder system for the exhalative sulphides. Characterized by partial to complete alteration and replacement of basaltic breccias (and flows?) by silica and sulphides. Total primary sulphide content averages 20% to 50%.

MINERALIZED BASALT: Transition zone between the silica stockwork feeder system and non-mineralized basalt. Total sulphide content less than 20%.

DBF: "Debris Flow" - Talus deposits which formed at the base of high-angle fault scarps in the original depositional basin. Individual debris flows can include fragments of basalt, mudstone, chert, and sulphides, with lesser amounts of gabbro, and are commonly highly sheared.

SERPENTINITE: Partial to completely serpentinized mantle peridotite (and dunite?).

FAULT — CONTACT — ROAD

Plate 1. Simplified schematic block diagram of the Turner-Albright massive sulfide deposit.

mine, but both hemipelagic and local sources probably contributed to the formation of the muds. Local increases in the silica content of the sediments indicate an exhalative or biogenic source for at least a portion of the material. Radiolarians have been observed in several of the more siliceous mudstones, and confirm an approximate 155-m.y. date for the ophiolite (Harper, personal communication, 1984). Thin (up to 1-m-thick) mudstone layers commonly cap the exhalative horizons and appear to be laterally more extensive than the sulfide bodies themselves, as several mud horizons extend beyond the known limits of sulfide mineralization. At least two, and possibly three, additional clastic horizons have been identified at the Turner-Albright but are not known to be associated with sulfide development.

Basin-floor rubble: From an examination of textures associated with the sulfide bodies located at the Turner-Albright, it is apparent that a large portion of the deposit occurs as a replacement of brecciated basalt fragments. The basin-floor rubble (Figure 4) represents accumulations of up to 75 m of brecciated basalt that covered the original depositional basin prior to the onset of hydrothermal activity and the venting of the sulfide horizons. The majority of the silica stockwork sulfides, as well as a large portion of the massive sulfide horizon, may occur within highly altered portions of this unit. Intense hydrothermal alteration within this section of the Turner-Albright stratigraphy obscures the composition of many of the fragments; however, it is apparent that fragments of the mafic lava series form the majority of the unit, with clasts of the regionally dominant plagioclase-bearing lava generally restricted to the base of the rubble pile.

Talus deposits: High-angle faulting associated with the formation of the Turner-Albright deposit resulted in several moderate- to high-relief fault scarps in the original depositional basin. Brecciation and erosion led to the accumulation of talus deposits at the base of these structures. Individual talus piles can include fragments of basalt, mudstone, and sulfides, with minor amounts of gabbro. The talus deposits commonly have been subjected to a high degree of internal shearing. Sulfides occur as angular to subrounded fragments derived from preexisting, faulted exhalative and stockwork horizons, as well as replacement deposits formed by later fluid movement through units. As defined at the Turner-Albright, the talus deposits are differentiated from the basin-floor rubble by their stratigraphic position at the top of the sulfide horizons, their lack of extensive hydrothermal alteration, and the presence of mineralized fragments derived from the existing sulfide bodies. It is likely, however, that portions of the basin-floor rubble may actually represent pre-mineralization talus deposits and may account for mineralized areas containing plagioclase-bearing lava fragments within the predominantly mafic basin-floor rubble.

Sheeted dikes: Ophiolitic sheeted dikes are characterized by subparallel diabasic dikes and are interpreted to represent the conduits for the magma that supplied the overlying extrusive flows and pillows. The upper and lower contacts of the unit as a whole are commonly gradational. The upper transition zone with the extrusive lavas is composed of diabasic dikes with a downward decreasing proportion of basaltic screens, while the lower contact zone with the massive gabbro is characterized by extremely erratic and confusing diabase/gabbro textural variations.

Due to faulting that has completely removed the lower portions of the ophiolite, only the uppermost portion of the upper transition zone remains at the Turner-Albright. This portion of the Turner-Albright stratigraphy is poorly exposed and has been identified only in several drill holes in the northwest portion of the deposit and in extensively weathered outcrops in fault contact with serpentinite. Individual dike margins are marked by chill zones up to 1 cm across and are often brecciated. Moderate to locally intense epidote alteration is common. Textures within the cores of individual dikes and the enclosing basaltic screens are often indistinguishable, which makes identification of this transition zone extremely difficult in outcrop where the chill and/or breccia margins are generally obscured.

Peridotite/serpentinite: Partially to completely serpentinized mantle peridotite occurs immediately west of the Turner-Albright in the headwaters of the North Fork of the Illinois River. Pods of serpentinized dunite also occur and may represent primary cumulate differentiation within the upper mantle. Mafic pegmatite and rodingite dikes are common along the faulted contact with the extrusive basalt/sheeted dike transition zone, as well as in shear zones within the peridotites. Thin (1- to 3-cm-thick) seams of powdered magnetite also occur locally along the contact. The serpentinites are highly magnetic relative to the other units in the vicinity and can be readily located by their magnetic signature.

Mineralization

Sulfide minerals identified at the Turner-Albright include pyrite (± marcasite), sphalerite, chalcopyrite, and linnaeite, with trace amounts of tetrahedrite, stannite, galena, and pyrrhotite. While assumed contributions from multiple vent sources and extensive post-mineralization faulting complicate any study of the primary zonation patterns, it appears that the original metal distribution resulted in copper/gold-rich centers at depth within the basin-floor rubble and proximal to the vents, with zinc/silver and pyrite with cobalt zones occurring with increasing distance from the venting sites. Limited thin- and polished-section work indicates that the metallurgical characteristics of the deposit are complex and may complicate extraction of the base and precious metals. Fine-grained chalcopyrite and sphalerite are tightly intergrown with pyrite and, to a limited extent, with each other. Gold occurs as discrete micron-sized blebs within chalcopyrite (and, to a limited extent, sphalerite) and pyrite. This gold/pyrite association results in low to locally moderate gold values (0.02 to 0.07 oz/ton) in the distal pyrite halo in the absence of any base metal credits. Cobaltiferous linnaeite occurs as rims on pyrite grains. Porous colloform marcasite is most abundant in the uppermost portion of the deposit and may in part be a product of near-surface alteration of the primary ion sulfides. It must be stressed that these findings are fragmentary and that a final metallurgical definition of the deposit remains to be made.

As currently defined, the sulfide bodies at the Turner-Albright are composed of three interrelated types of mineralization (Figure 4). Massive sulfide horizons up to 30 m thick and containing >50 percent total sulfide content occur at the stratigraphic top of

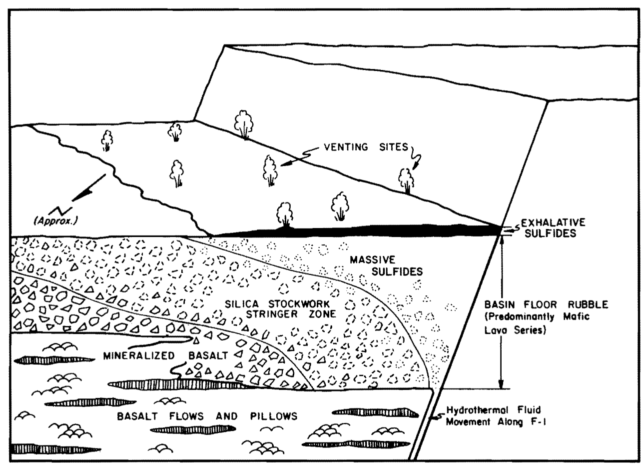


Figure 4. Stratigraphic cross section during the late stages of the development of the Turner-Albright deposit and prior to the deposition of the clastic (±silica) mudstone horizon.

the mineralized section. A silica stockwork stringer zone consisting of highly altered breccias occurs below and lateral to the massive sulfides. Total sulfide content generally decreases to trace amounts in the stringer zone with distance from the main exhalative centers, resulting in a third definable horizon, termed a mineralized basalt, which contains less than 20 percent total sulfides. The potentially economic portions of the deposit are generally restricted to the massive and stringer horizons but are not necessarily associated with the greatest sulfide content. A large percentage of the massive horizon at the northern end of the deposit is composed essentially of massive pyrite/marcasite and is of a relatively low economic grade. Where exposed at the surface, all three units oxidize to form gossans or "llozzans"* that mark the updip, western limit of the deposit. Limited outcrop sampling and shallow drilling support the interpretation that the majority of the gossans (and "llozzans") were derived from portions of the deposit with a relatively low gold content and therefore have little potential to develop substantial reserves of leachable ore.

The massive sulfide horizons that occur at the Turner-Albright are interpreted to have been formed either as seafloor exhalites or by the extensive alteration and replacement of basaltic breccias resulting in nearly complete obliteration of all primary textural features. Evidence of brecciation within the massive horizon commonly increases at lower stratigraphic levels, with ghosts of almost completely replaced basaltic clasts grading into highly mineralized rock with identifiable basalt and chert(?) fragments. It is probable that many or all of the chert fragments, which are commonly nonmineralized, are actually completely silicified basaltic glass. The origin of any given portion of the massive horizon (i.e., exhalite or total replacement) may be difficult to determine due to this extensive alteration, and it is often impossible to define the original rock/water interface. From the amount of basaltic fragments within the sulfide horizons, it is clear that the majority of the mineralization at the Turner-Albright was the result of partial to complete replacement of basaltic breccias. The uppermost portion of the massive horizon, however, commonly exhibits fragmental textures, and it is possible that some of this sulfide brecciation may represent collapsed chimney structures that were initially built by the venting of sulfide-rich fluids on the sea floor. In addition, several small worm casts (1-2 mm in diameter) have been tentatively identified. These two bits of evidence support an exhalative seafloor origin for the upper 1-3 m of the deposit.

At the Turner-Albright, the silica stockwork stringer zone contains from 20 to 50 percent primary sulfides and represents a conformable transition from essentially complete replacement of basaltic breccias to nonmineralized flows, pillows, and hyaloclastites. The contact between the silica stockwork zone and the overlying massive sulfides (as well as with the more distal mineralized basalt) is gradational, and the actual location is somewhat irregular and arbitrary. The silica stockwork is almost certainly a result of the percolation of mineralizing fluids through basaltic rubble and is characterized by silica flooding of the breccias, with the addition of pyrite ($\pm$ marcasite), chalcopyrite, sphalerite, and accessory sulfide minerals. Mineralized flows and/or pillows have not been identified within the silica stockwork. Hydrothermal penetration of the breccia pile resulted in substantial alteration of the original rock (silica+sulfides+chlorite+albite). From a study of partially altered fragments within the silica stockwork, it is apparent that the majority of the clasts are related to the mafic lavas discussed above. The degree of mineralization and the economic value of the silica stockwork stringer zone are both somewhat erratic. This may in part be due to the original configuration of the rubble pile, with areas of higher mineralization reflecting increased fluid movement along paths of greatest permeability.

Mineralized basalt includes the portions of the volcanic breccias and flows that were subjected to alteration by hydrothermal fluids'but that contain a total sulfide content of less than 20 percent. Preliminary relogging of selected drill core indicates that, while some of the breccia fragments are related to the mafic lavas, clasts of the plagioclase-bearing lava series occur. It is also evident that mineralization within flow units, as opposed to being restricted to altered breccias, occurs to a limited extent at the northern end of the deposit. An increase in hematitic alteration has also been noted within breccias and flows that occur stratigraphically below and lateral to the sulfide-rich portions of this unit. The mineralized basalts, which are generally of very low economic grade, are interpreted to represent the most distal effects of the mineralizing fluids.

Structure

The majority of the known sulfides at the Turner-Albright occur as three vertically stacked horizons that trend northeast with a moderate southeast dip. These three zones occur in two, and possibly three, separate time-stratigraphic horizons, and have been designated the Upper High-grade Zone (UHZ), the Main Upper Zone (MUZ), and the Main Lower Zone (MLZ). Post-mineralization faulting has broken the MUZ and MLZ into somewhat discrete fault-bounded mineralized blocks; however, in many cases the original thickness of the disrupted sulfide horizon was greater than the displacement along the fault, so that when the fault is intercepted in drill core, no readily discernible lithology change occurs across the structure. This is especially true in the MUZ, which is up to 100 m thick. A minimum of three generations of faulting (pre-mineralization, post-mineralization, and emplacement) have been recognized to date. Additional and extensive faulting severely disrupts the stratigraphy associated with the UHZ.

A complex series of pre- and post-mineralization high-angle northwest-trending normal faults have been partially defined (F-series faults). At least five separate structures (F-1 through F-5) (Figures 3 and 5) have been identified within the known sulfide horizons, and there is evidence of additional faulting south of the deposit. Outcrop measurements and correlations between drill intercepts indicate that the F-series faults strike approximately N. 60° W. and dip to the north from 65° to 85°. The pattern is complicated by poorly defined branching and interconnecting near-vertical east-west splay faults.

The southernmost structure, F-1, is interpreted to have existed prior to the onset of hydrothermal activity and to have controlled the movement of the primary mineralizing fluids. While there is no evidence to indicate that other F-series faults predate the mineralization, the possibility of hydrothermal penetration and/or pre-mineralization movement along some or all of the remaining F-series faults cannot be ruled out. Post-mineralization movement along the F-series faults disrupted the stratigraphy immediately after deposition of the sulfide horizons, with a resulting downdropping of the overall sulfide horizon to the northeast (Figure 5). Timing of post-mineralization activity along the F-series faults is bracketed by the deposition of the sulfide horizons and the extrusion of the thick gabbroic-textured flows that generally appear to have been unaffected by their movement. Post-mineralization displacement, calculated by measuring the offset of the tops of adjacent sulfide horizons, averages 30-40 m. Due to the steepness of the structures and their orientation normal to the strike of the sulfide horizons, standard cross sections are not sufficient to fully define their characteristics. A series of horizontal and longitudinal sections are currently being prepared

*"Llozzan" is a term coined by the writer to describe "gossanlike" material derived from the oxidation of sulfide-bearing rocks containing less than 50 percent total primary sulfide minerals. The term is in honor of Lloyd Frizzell, whose faith in the "llozzans" at the Turner-Albright kept the project alive through the early days of exploration in the 1960's and 1970's.

to aid in reconstruction of the original depositional setting and interpretation of these critical structures.

A later series of low-angle east-west-trending post-mineralization reverse(?) faults is indicated (R-series faults) (Figure 3). Timing of the R-faults is unknown, but it is possible that these structures were associated with the emplacement of the Josephine Ophiolite along the continental margin, as well as with the faulting and removal of the lower portion of the ophiolite at the Turner-Albright. At least three R-series faults have been identified to date (R-1, R-2, and R-3). Three-point structural calculations and outcrop measurements indicate that these faults strike generally east-west and have a very shallow north dip (approximately 20°). The major impact of these low-angle structures was along R-1, where an apparent 150-200 m of displacement resulted in dislocation of the original single sulfide horizon into the MUZ and MLZ. Offsets along R-2 and R-3, which are located above R-1, are minor and generally do very little to disrupt the MUZ. It is probable that additional R-series faults exist within the MLZ. It is important to note that the R-series faults cut and displace the F-series faults, which greatly complicates any attempt to reconstruct both the original setting of the deposit and the geometry of the depositional basin. The ultimate effect of all these structures on the Turner-Albright stratigraphy is still poorly understood, and it is probable that a full understanding will require underground mapping.

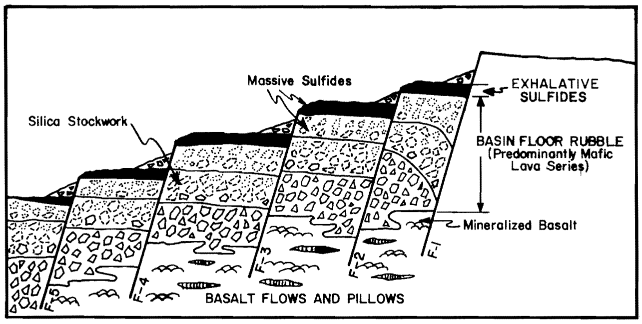


Figure 5. Cross section through the Turner-Albright deposit prior to dislocation along the R-series faults and emplacement along the continental margin.

Sulfide geometry and exploration potential

The uppermost sulfide horizon (UHZ) is relatively thin (2-15 m) but of very high grade and located within 25 m of the surface. Drill-indicated reserves for the heart of the UHZ total 50,000 tons at an average grade of 0.40 oz/ton of gold, 1.70 oz/ton of silver, 4.30 percent copper, 1.35 percent zinc, and 0.08 percent cobalt. Geologic and structural interpretations indicate that the UHZ is laterally extensive and directly overlies the MUZ toward the southern end of the deposit, with a thickening wedge of basalt, mudstone, and/or hyaloclastite separating them to the north. There is also evidence that mineralization associated with the UHZ overlies portions of the MLZ as well, which supports the theory that a single sulfide horizon was faulted into the MUZ and MLZ along R-1. Extensive post-mineralization faulting at the north end of the deposit has severely disrupted the UHZ. Drilling to date has delineated the known zone both along strike and updip. The potential is good for locating additional mineralization to the southeast (downdip), as well as faulted portions to the north.

The relationship between the MUZ and MLZ, which contain the bulk of the reserves, is uncertain at this time. Drill-indicated reserves for the combined MUZ and MLZ total approximately 3 million tons at an average grade of 0.12 oz/ton of gold, 0.60 oz/ton of silver, 1.55 percent copper, 3.70 percent zinc, and 0.05 percent cobalt.

The majority of mining engineers who have examined the Turner-Albright have indicated that the MUZ may be amenable to surface mining methods. Preliminary estimates of waste to ore ratios are fairly high, however, and without a substantial increase in pittable reserves, the MUZ would probably have to be developed from underground. The possibility of significantly expanding reserves associated with the MUZ is relatively poor. The general boundaries of the MUZ have been well defined and consist of surface outcrop (updip), R-1 (downdip), F-1 (southwest), and the serpentinite (northeast) (Figure 3). From the suggested fault pattern, several unexplored wedges still exist within these limits, which could increase reserves in the MUZ by as much as 250,000 to 300,000 tons of potentially economic ore. In addition, approximately 1 to 1.5 million tons of mineralized basalt, containing from 0.02 to 0.07 oz of gold and 2 to 5 lb of cobalt to the ton, occur within the northern part of the deposit. This portion of the Turner-Albright, while of subeconomic grade at current metal prices, would represent a substantial cobalt/gold reserve given the proper economic conditions. The inclusion of these units as minable reserves would help in reducing the waste to ore ratio to a level acceptable for surface mining methods.

Table 1. *Approximate drill-indicated reserves*

Zone	Tonnage	Gold (oz/ton)	Silver (oz/ton)	Copper (%)	Zinc (%)	Cobalt (%)
UHZ	50,000	0.40	1.70	4.30	1.35	0.08
MUZ	1,600,000	0.13	0.50	1.40	3.00	0.05
MLZ	1,400,000	0.10	0.75	1.75	4.50	0.04

Because of its depth below the surface, the MLZ would require underground mining methods. The base of the known ore body could be reached by a 3,500-ft-long crosscut driven from the east. The possibility of doubling or tripling the MLZ reserves is considered excellent. Structural, geologic, and geophysical evidence indicates that mineralization may extend to the southeast down the plunge of F-1 for a considerable distance. Detailed pulse-electromagnetic geophysical work during the summer of 1985 was successful in defining the known mineralization and indicates that a two- to three-fold increase in MLZ reserves is probable. Due to the increasing depth of the mineralization, however, the pulse-electromagnetic system was unable to define the southeastern limit of the MLZ. Because of this depth of penetration limit, the suggested increase in the size of the zone is considered a minimum value. Recent drilling by Rayrock Mines (prior to the pulse-electromagnetic survey) also indicates that substantially greater thicknesses of high-grade mineralization occur downdip from the deepest intercepts of either Baretta or Noranda. Mineralization encountered in these deep holes is characterized by very high zinc values at the stratigraphic top of the sulfides (>10 percent over 25-m true widths) and increasing copper/gold values near the base of the section. Because chalcopyrite is highly conductive and sphalerite is nonconductive and therefore generally invisible to electromagnetic readings, it has been interpreted that the indicated additional reserves may contain a relatively large percentage of chalcopyrite (Crone, 1985).

Discussion

The Turner-Albright is interpreted to be an ophiolitic, volcanogenic sulfide deposit that was the product of replacement and exhalative processes within a back-arc rifting environment. Convection of oceanic waters that were superheated by ascending (and differentiating) magmatic mantle material resulted in the leaching of sulfur, iron, cobalt, zinc, gold, silver, and copper from the mafic and ultramafic pile, with precipitation of silica and sulfides at or near the rock/water interface. Additional mineralization commonly occurred distal to the venting sites producing a silica stockwork that represents zones of large-scale hydrothermal penetration and replacement and, to a limited extent, the plumbing system that supplied the exhalative horizon. The actual portion of the massive sulfide horizon that was formed as a result of exhalative seafloor venting may be fairly small. The original depositional basin at the Turner-Albright apparently had an extensive cover of basaltic rubble, which could have had a direct effect on the ultimate strength of the exhalative process. The highly permeable nature of the breccias probably resulted in the spreading out of the mineralizing fluids into this clastic horizon prior to actual venting on the seafloor. Some of the mineralized breccias are compositionally different from all other lavas identified to date and are characterized by phenocrysts of olivine and/or chromium spinel in a groundmass of glass and radiating clusters of quenched pyroxene crystals. Mudstones (locally siliceous) occur at the stratigraphic top of the sulfide horizons. It is probable that the cherty muds are in part the result of the addition of excess silica to the seawater in the vicinity of the sulfide vents.

It is reasonable to infer a period of relative inactivity with respect to volcanism both during and immediately following the formation of the sulfide bodies at the Turner-Albright. This quiescent period would have allowed time for the formation of the existing sulfide horizons and the accumulation of the mudstones. From recent work in the Josephine and other ophiolites, Harper (personal communication, 1986) postulates that magma chambers that feed the extrusive basalts experience cyclical periods of activity, followed by periods when they are essentially frozen and inactive. Partial crystallization of the upper differentiated portions of the magma chamber would possibly allow deeper, less mature lavas to escape and may account for the extrusion of the mafic lava series at the Turner-Albright. It is important to note that the introduction of the sulfides at the Turner-Albright immediately followed the accumulation of the mafic basin-floor rubble, and it is reasonable to assume that the same series of events contributed to both of these apparently anomalous (in a time-stratigraphic sense) events.

Subsequent to the formation of the deposit, the Turner-Albright was subjected to regional emplacement metamorphism and at least two generations of post-mineralization faulting. This structural breakup of the deposit complicates a full geologic and genetic understanding of the Turner-Albright and will certainly have an effect on any future mine plans.

Contemporary geologic studies often categorize mineral deposits by genetic "type," and much effort has been made over the past several years to define the Turner-Albright as a Cyprus-type deposit. While there are many similarities in gross geological features, it is the writer's opinion that there are significant differences between the Turner-Albright and the classic Cyprus-type deposits and that they represent different subtypes of ophiolite-hosted massive sulfide deposits. The writer proposes that a separate classification be considered for the Turner-Albright and that it be classified as a "Josephine-type" deposit based upon the following characteristics:

(1) The Turner-Albright is ophiolite hosted and occurs intimately associated with seafloor volcanism and extensional tectonics. Mineralization is structurally controlled and is restricted to the lowest portions of the extrusive lava series immediately above the sheeted dike/extrusive rock transition zone.

(2) Features common to the Cyprus deposits, including umbers, ochres, "vertically extensive stringer zones," and "extensively altered footwall rocks" (Franklin and others, 1981) have not been identified at the Turner-Albright. Iron-poor, locally siliceous mudstones occur at the Turner-Albright in the same relative stratigraphic position as the Cyprus ochres.

(3) More than 90 percent of the known sulfide mineralization at the Turner-Albright is the result of large-scale replacement of basaltic breccia and talus. The original depositional basin had a cover of up to 75 m of highly permeable basaltic rubble that is compositionally different from both the footwall and hanging-wall basalts. The permeable nature of the breccias had the effect of dissipating the mineralizing fluids into this clastic horizon prior to venting on the seafloor, with only a minimal amount of the hydrothermal fluids reaching the rock/water interface to form exhalative sulfides.

(4) A true silica stockwork zone, in which hydrothermally altered flows and pillows stratigraphically below the massive horizon represent the feeder system for the overlying exhalative sulfides, does not occur at the Turner-Albright. The silica stockwork at the Turner-Albright is the result of extensive hydrothermal penetration and replacement of basaltic breccias, and in only a very limited sense does it represent the feeder system for the exhalative horizon.

(5) The sulfide bodies at the Turner-Albright have anomalously high gold values. As currently defined, the Turner-Albright contains approximately 6.5 million tons (including the mineralized basalt) with an average gold content of 0.055 oz/ton. Significantly greater values (up to 0.462 oz/ton over a 15-m true width) are found within the higher grade portions of the deposit, and the potentially economic portion averages 0.12 oz/ton.

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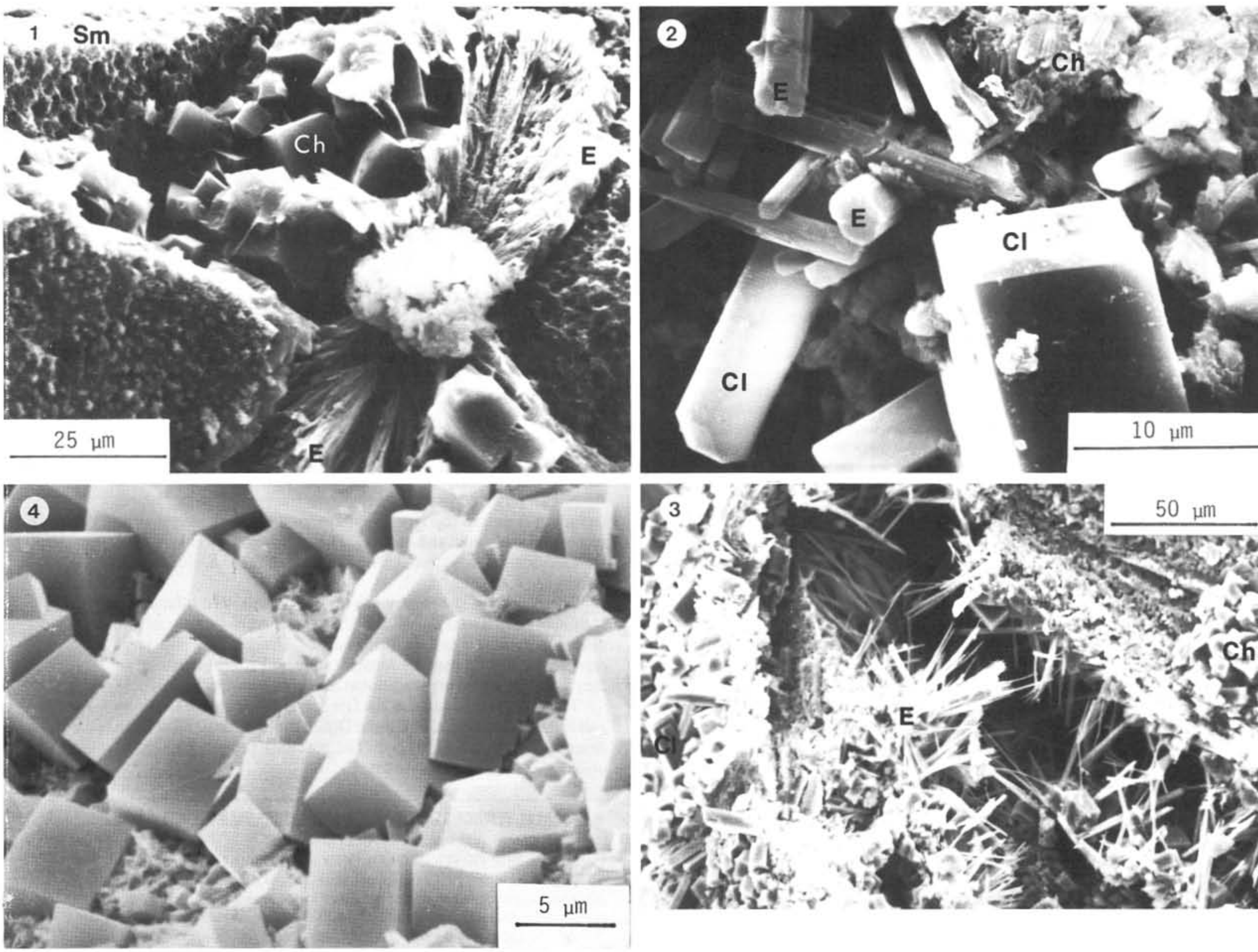

THIS MONTH:

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

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COVER PHOTOS

Four scanning electron micrographs of specimens from the Durkee zeolite deposit discussed in article beginning on next page. 1. Chabazite and erionite on a clay substrate in a cavity from unit 3GY. 2. Erionite and clinoptilolite from tuff bed at unit 11. 3. Cavity between platy shards preserved by clay coating, from tuff bed at unit 14B. 4. Chabazite rhombs and twinned (0001) rhombs on clay mat from tuff bed at unit 16. Letters on micrographs identify Ch=chabazite, CL=clinoptilolite, E=erionite, SM=smectite.

OIL AND GAS NEWS

ARCO continues Mist drilling program

With two successful wells in the summer, ARCO Oil and Gas Company continues its program of drilling at Mist. The company has drilled three wells since the last producer was completed and has about three more wells planned for 1986.

As reported last month, Cavenham Forest Industries (CFI) 33-9 was drilled to 3,242 ft and was plugged and abandoned. In addition, CFI 41-4 and a redrill 41-4 have been drilled to 2,584 ft and 1,935 ft, respectively, and plugged. Finally, CFI 12-12 was drilled in September to a total depth of 1,862 ft and was also plugged as a dry hole.

CFI 41-9 is the next well on ARCO's 1986 program.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
377	ARCO Longview Fibre 11-31 009-00214	NW¼ sec. 31 T. 6 N., R. 4 W. Columbia County	Application; 2,300.

□

Survey describes map revision needs in Oregon

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released results of a survey of State agency needs for map revisions. The findings have been published in DOGAMI Open-File Report 0-86-17 under the title *Map Revision Requirements of Oregon State Agencies.* The report was prepared for the State Map Advisory Committee by Glenn W. Ireland, State Resident Cartographer.

The survey addresses the needs of 14 State agencies, all of which coordinate their mapping through the State Map Advisory Committee. It investigates seven major map series used in the state, computerized maps as well as traditional paper maps, including standard topographic maps used for such purposes as recreation, camping, and hunting. The survey was a joint effort of DOGAMI and the National Map Division of the U.S. Geological Survey.

The results of the survey are intended mainly to inform the National Map Division of the U.S. Geological Survey of the mapping requirements in the State of Oregon. The 40-page report will also be used by local, State, and Federal agencies as they jointly plan future traditional and computerized maps.

The report is available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, OR 97201. The purchase price is $5. Orders under $50 require prepayment. □

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Beverly F. Vogt, Publications Manager.

Field trip guide to the Durkee zeolite deposit, Durkee, Oregon

by R.A. Sheppard, U.S. Geological Survey, Denver Federal Center; and A.J. Gude, 3rd, U.S. Geological Survey, retired, Lakewood, Colorado

This article is a slightly modified reprint of "Field Trip Stop 1, Durkee Zeolite Deposit, Durkee, Oregon," which originally appeared in *Zeo-Trip '83*, a publication of the International Committee on Natural Zeolites that was used as guide for the organization's field trip held from July 7 to 10, 1983. The book, which was edited by F.A. Mumpton, State University College, Brockport, New York, and prepared by R.A. Sheppard, A.J. Gude, 3rd, and F.A. Mumpton, also contains trip logs to the Sheaville and Rome zeolite deposits in Oregon; the Castle Creek zeolite deposit in Oreana, Idaho; the Lovelock zeolite deposit in Lovelock, Nevada; and the Tahoe-Truckee water reclamation plant in Truckee, California. In addition, there is a section on the discovery and commercial uses of the zeolite deposits described in the book. Upcoming issues of *Oregon Geology* will contain reprints of the trip stops at Sheaville and Rome, both in Oregon. Copies of *Zeo-Trip '83* may be purchased prepaid for $12 from International Committee on Natural Zeolites, c/o Department of Earth Sciences, SUNY, College at Brockport, Brockport, New York 14420. Permission to reprint the Oregon trip stops in *Oregon Geology* is gratefully acknowledged.

— *Editor*

INTRODUCTION

The Durkee zeolite deposit is located about 5 km east of the hamlet of Durkee, Baker County, Oregon, and 145 km northwest of Boise, Idaho. Interstate Highway 84 transects the northwest-trending Durkee Valley, which is drained by the Burnt River and tributary streams. The field trip stop described in this article is in the SE¼ SE¼ sec. 23, T. 11 S., R. 43 E., and is easily accessible by Manning Creek Road from Interstate Exit 328. Figure 1 shows the geologic setting and other geographic features.

Nearly 100 m of zeolitic rocks is exposed at this locality in an amphitheater that has been produced by differential erosion (Figure 2). The steep cliff walls and pinnacles are formed by weathering-resistant zeolitic tuffs. Part of the light-colored lacustrine rocks present in Durkee Valley are visible in the distance from the amphitheater rim. The crudely elliptical area of the lacustrine Durkee basin is about 120 km². Within this area, authigenic zeolites are restricted to an irregular, nearly sinusoidal, 18-km² area in the southeastern part of the basin. Within the mapped area of Figure 1, the topographic relief is about 660 m; the low point on the Burnt River is at an elevation of about 780 m, and the highest point in the northeast corner of the mapped area is about 1,440 m above sea level.

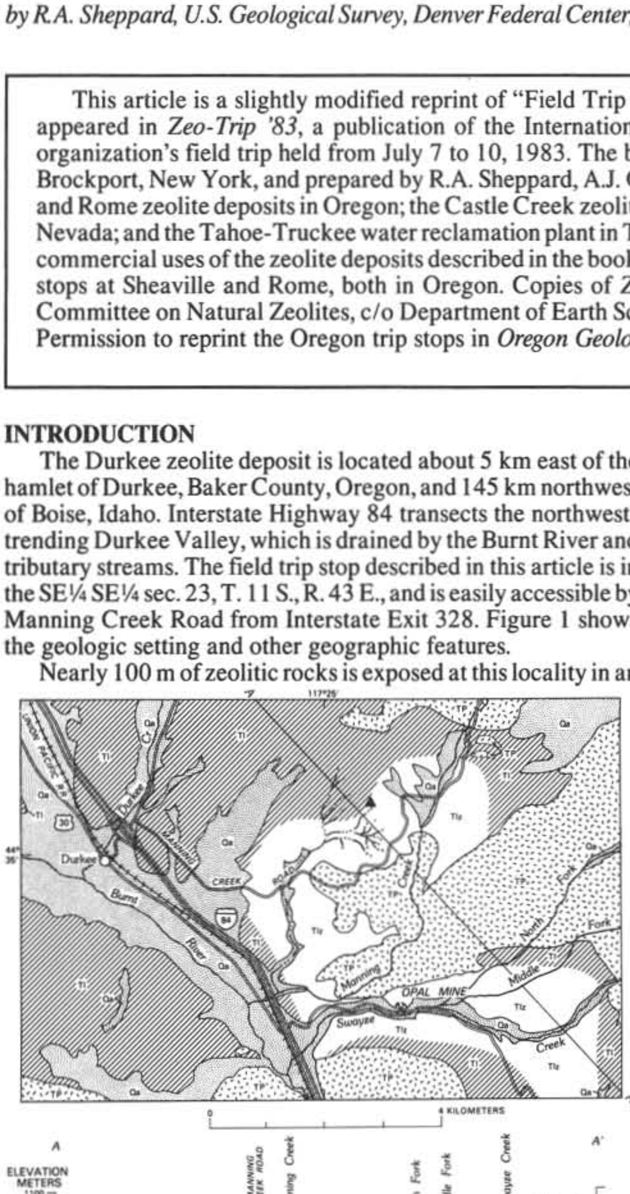


Figure 1. Generalized geologic map of the Durkee, Oregon, area, showing the location of the field trip stop discussed in this paper. Map is modified from Prostka (1967).

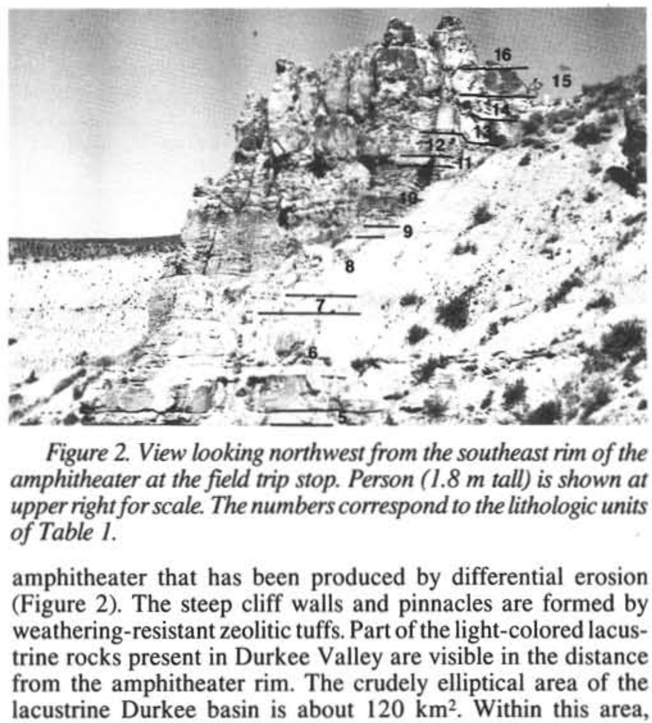


Figure 2. View looking northwest from the southeast rim of the amphitheater at the field trip stop. Person (1.8 m tall) is shown at upper right for scale. The numbers correspond to the lithologic units of Table 1.

Most of the 18-km² area of zeolite-bearing rocks is shown by symbol **Tlz** in Figure 1. A 1.8-km² part of the zeolitic area is beyond the southeast corner of the map. Pre-lacustrine sedimentary, metamorphic, and igneous rocks bound the margins of the larger lake basin. Unconsolidated alluvial and fluvial Holocene (recent) sediments fill most of the stream bottoms and form gravel benches on both the lacustrine formations and the surrounding older rocks. Figure 1 is adapted and modified from Prostka's (1967) geologic map of the Durkee 15-minute quadrangle. An unnamed Pliocene deposit of "tuffaceous lake and stream sediments," shown in Figure 1 by symbol **Tl**, crops out over a 120-km² area. The lake sediments are about 340 m thick and consist of mudstone, siltstone, sandstone, and diatomite with interbedded airfall tuffs and a welded ash-flow tuff near the

Table 1. Mineralogical composition of measured section at field trip Stop 1, Durkee zeolite deposit, Baker County, Oregon.

Unit	Lithology	Thickness (m)	Height above base of unit (m)	X-ray diffraction analysis[1] (in parts of ten) Ch	Cp	Er	Glass	C-T	Pl	Qtz	Sm
(Top of unit 16 not exposed)											
16	Tuff, yellow, coarse shard texture	3.96	2.45	10	-	tr	-	-	-	-	tr
15	Tuff, yellow-gray, pumice fragments as large as 5 cm	2.04	1.00	1	-	-	-	-	-	-	9
14B	Tuff, yellow to white, coarse shard texture	1.68	1.36	10	-	tr	-	-	-	-	-
14A	Tuff, yellow to white, coarse shard texture		0.91	4	tr	1	-	-	-	-	5
13	Tuff, yellow, coarse shard texture	1.68	0.85	7	3	-	-	-	-	-	tr
12	Tuffaceous mudstone, brown	1.40	0.70	tr	-	tr	-	-	-	2	8
11	Tuff, yellow	1.83	0.91	5	4	1	-	-	-	-	-
10	Tuffaceous mudstone, brown	3.81	1.90	tr	1	-	-	-	4	-	5
9	Tuff, yellow, pumice fragments up to 3 cm	0.79	0.40	3	1	-	-	-	2	-	4
8	Tuff, brown, punky, pumice in lower part	4.07	2.04	6	2	-	-	-	-	-	2
7	Tuff, brown, punky	0.70	0.35	2	3	-	-	-	-	-	5
6	Tuff, yellow, pumice fragments up to 1 cm	5.18	2.59	9	1	tr	-	-	-	-	-
5	Tuff, yellow, laminated, resistant	0.52	0.26	10	tr	tr	-	-	-	-	-
4	Mudstone, brown, poorly exposed	17.07	0.91	-	-	-	-	-	-	1	9
3G	Welded tuff, white, altered	1.22	1.20	9	-	tr	-	-	1	-	-
3GX	Welded tuff, gray, fresh		1.00	1	-	1	8	-	-	-	-
3GY	Tuff, altered along joint at GX		1.00	7	-	1	2	-	-	-	-
3F	Welded tuff, gray, platy, glassy	1.22	0.61	-	-	-	10	-	tr	-	-
3E	Welded tuff, gray, blocky fracture	2.44	0.30	-	-	-	-	5	5	-	-
3D	Welded tuff, greenish, blocky fracture	7.62	0.91	-	-	-	-	6	4	-	-
3C	Welded tuff, olive-green, blocky fracture	1.07	0.53	-	-	-	10	-	tr	-	-
3B	Welded tuff, gray, charcoal fragments	3.05	2.75	-	-	-	10	-	-	-	-
3A	Welded tuff, yellow, altered		0.15	-	-	-	-	-	-	-	10
2	Tuff, white, thin-bedded	0.91	0.45	10	-	-	-	-	-	-	-
1	Mudstone, yellow-brown	4.57	3.00	-	1	-	-	-	2	2	5
(base of unit 1 not exposed)											

[1] Ch = chabazite; Cp = clinoptilolite; Er = erionite; C-T = opal C-T; Pl = plagioclase; Qtz = quartz; Sm = smectite (14-Å clay mineral); tr = trace; - = looked for but not found.

bottom of the sequence. The enclosing rocks, shown by symbol **TP**, range in age from Permian to Tertiary. They include "greenschist," gabbro, the Nelson marble (which is being quarried southwest of Interstate Highway 84 near the southeast corner of the mapped area of Figure 1), quartz diorite, and patches of basalt of the Columbia River Basalt Group.

Small-scale faults, probably associated with a northwest-trending set of normal faults on Prostka's map (1967), have offset the tuff units visible in the amphitheater (Figure 2). One such fault has displaced the beds in the southwestern wall of the amphitheater. Similar displacement is found throughout the basin and makes mapping and correlation of the tuff units nearly impossible, except where the welded tuff is in an undisturbed sequence. In their report on the geology of the Oregon part of the Baker 1°x2° quadrangle, Brooks and others (1976) postulated that "The source of the ash ... may relate to the eruption of large volumes of silicic ash from vents in Harney Basin during Pliocene time." Harney Basin is 225 km southwest of Durkee.

The original discovery of erionite was made at the Opal Mine, along Swayze Creek, in the southeastern portion of Figure 1. A.S. Eakle (1898), a mineralogist at Harvard University, credited E. Porter Emerson for the discovery, but no further information is available on Emerson's identity. More than half a century passed before Staples (1957) relocated the Opal Mine and reexamined the type material (Staples and Gard, 1959). The Opal Mine quarry may have once had some underground workings, but the existing site is a chaotic pile of welded-tuff rubble that has been disturbed by construction of the present road that obliterated much of what may have been a waste dump. Frequent mineral collecting has removed most of the gemmy fire opal and all but tiny fragments of the woolly erionite. Since the original work by Eakle in 1898, the site has deteriorated to such an extent that no "type" erionite can be found in place, and collectible specimens in the form of fragments require hours of search to find.

Sheppard and Gude (1975) visited the Opal Mine quarry in 1970 to collect the type erionite and reported the existence of a lacustrine basin and authigenic minerals, including zeolites, in altered tuffs above and below the welded ash-flow tuff that is present in the mine area. Details on the mineralogy of the Durkee chabazite were given by Gude and Sheppard (1978), and the chemistry of other zeolites and zeolitic tuffs of the region was reported by Sheppard and Gude (1980). The Durkee deposit has not been commercially exploited for zeolites, although several companies have examined the area and prospected the deposit.

STRATIGRAPHY, LITHOLOGY, AND DEPOSITIONAL ENVIRONMENT OF THE BASIN DEPOSITS AT DURKEE

Information on the stratigraphy, lithology, and environments of deposition in the lacustrine basin at Durkee is scant. Prostka (1967) briefly noted the work done prior to his mapping, but since then, the only reported studies of this area have been made by the present authors. A composite, 340-m stratigraphic column through the deepest part of the basin as presented in Gude and

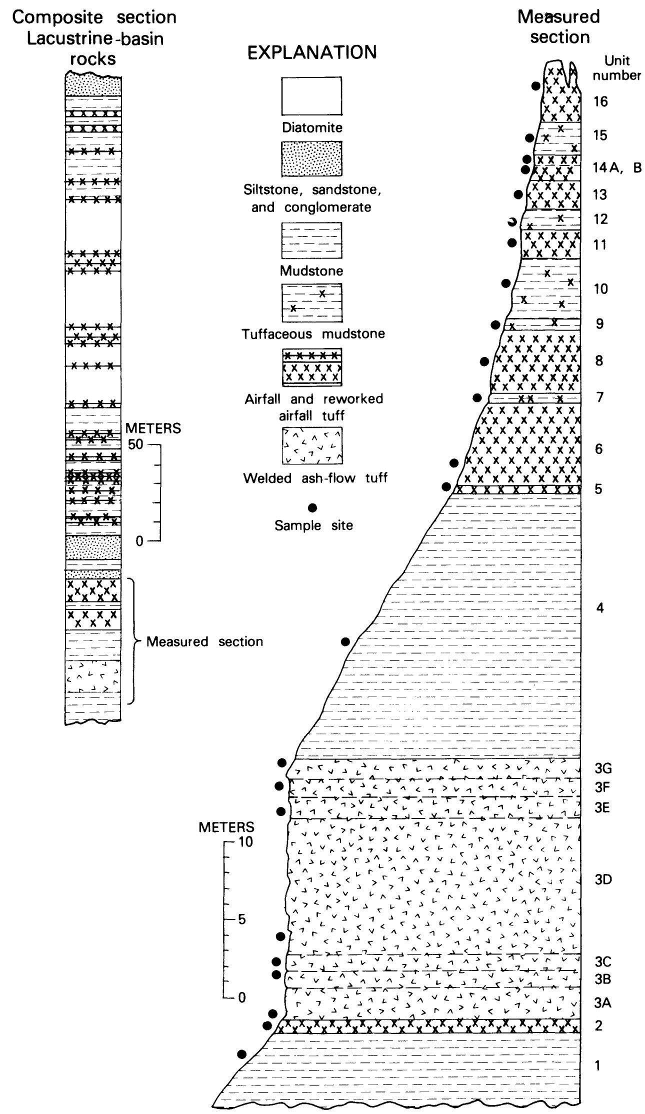


Figure 3. Composite columnar section of the lacustrine rocks in the Durkee basin and profile of the measured section at the field trip stop. The unit numbers correspond to the lithologic units of Table 1.

Sheppard (1978) is shown in Figure 3 along with a profile of the 67-m section measured at the field trip stop. Figure 4 is a view across the basin towards the northeast from a point on old U.S. Highway 30, about 2 km east of Durkee. The amphitheater and its pinnacles are visible on the right (arrow, Figure 4), and the enclosing unaltered rocks are visible in the light-colored hills in the middle of the photo. The cross section shown in Figure 1 along A-A′ depicts the possible subsurface relationships across the middle of the basin from northwest to southeast.

Figure 4. Panoramic view toward the northeast from a point about 1 km southeast of Durkee on U.S. Highway 30, showing the lacustrine beds exposed at the head of Durkee Creek and in the amphitheater at the field trip stop. Arrow indicates the amphitheater and pinnacles shown in Figure 2.

The composite columnar section contains about 45 percent mudstone, 35 percent diatomite, 15 percent volcaniclastic rocks (10 percent airfall tuffs, 5 percent welded ash-flow tuff), and 5 percent sandstone, siltstone, and conglomerate. At least 32 distinct tuff units are shown in Figure 3, including the welded ash-flow tuff. Scattered remnants of Mazama ash are present in perched channels in the Holocene basin-fill alluvium. This widespread ash layer originated from the great eruption of Mount Mazama at the site of present Crater Lake, Oregon, about 6,600 years ago. Basalt, older than the lacustrine rocks, occurs just below the lake beds in thin irregular flows and patches at several places across the basin. One such patch is visible across Manning Creek Road adjacent to the study area.

The 18-km^2 area of zeolitic alteration of the tuffaceous rocks denotes a closed soda-lake environment such as those described by Sheppard and Gude (1968, 1969, 1973) and Surdam and Eugster (1976). Siliceous, vitric volcaniclastic material deposited in the highly alkaline, saline water reacted during low-temperature, low-pressure diagenesis to form zeolites and associated authigenic silicate minerals. In the rest of the basin, the lake remained fresh or brackish from stream water entering from the surrounding terrain. Thus, the equivalent tuff units beyond the saline, alkaline-lake part of the basin are unaltered and still glassy.

During the ongoing history of the Durkee basin in early Pliocene time (2 to 5 million years before the present [m.y. B.P.]), the lake never again became a closed, soda-lake system. The environment was favorable for flourishing diatom growth as preserved in the thick diatomite units shown in Figures 3 and 4. Many thin, unaltered tuffs are interbedded in the diatomite.

MINERALOGY AND CHEMISTRY OF THE ZEOLITIC TUFFS

Chabazite, clinoptilolite, and erionite are present in the tuffs and tuffaceous rocks in the 67-m measured stratigraphic section (Figure 3), except in the massive, glassy, welded ash-flow tuff. No zeolites were found in the 17-m thick mudstone (unit 4) above the welded tuff. The measured section is in the bottom quarter of the complete lacustrine sequence. The base of the section and of the mudstone (unit 1) is not exposed in this location. Evidence from other localities in the basin, however, indicates that the welded tuff is less than 5-7 m above the bottom of the lake basin.

The mineralogy determined by X-ray powder diffraction (XRD) analysis of bulk samples is given in Table 1. About 10 percent of the measured section is comprised of nearly monomineralic beds of chabazite. Chabazite mixed with minor amounts of erionite, clinoptilolite, and detrital minerals is present in another 20 percent of the section. Glassy, unaltered, welded ash-flow tuff makes up about 23 percent, and mudstone and tuffaceous mudstone account for the remaining 45-47 percent. Gude and Sheppard (1978) estimated that several million tons of chabazite may be present in the Durkee basin.

Although chabazite is the predominant zeolite in the immediate area of this stop, several resistant tuff beds of nearly pure erionite occur stratigraphically higher elsewhere in the basin. Most of these tuffs are 25-35 cm thick, but beds of mixed mineralogy up to 1 m thick also occur. Clinoptilolite has rarely been found in monomineralic beds, except in thin units less than 5 cm thick. Analcime and potassium feldspar have been found at sites away from the stop; for example, analcime-rich tuff crops out in the cut for Manning Creek Road, near the letter "R" of "ROAD" in Figure 1. Correlation of tuffs containing analcime and potassium feldspar with units in the measured section has not been established.

Table 2. Chemical analyses of selected silicic glass and siliceous chabazite, Durkee, Oregon.

	Glass[1,2] 1	2	Chabazite[3,4] 3	4
SiO_2	73.35	71.67	57.91	58.65
Al_2O_3	12.31	11.78	14.25	13.51
Fe_2O_3	1.06	0.71	0.42	0.61
FeO	0.81	1.24	0.02	0.00
MgO	0.08	0.19	0.40	1.27
CaO	0.48	0.81	3.85	3.78
K_2O	3.73	5.04	1.33	1.76
Na_2O	3.83	2.21	2.46	0.77
TiO_2	0.14	0.38	0.15	0.02
P_2O_5	0.01	0.03	0.03	0.01
MnO_2	0.04	0.04	0.01	0.00
CO_2	-	-	0.04	0.02
H_2O+	3.43	5.42	10.58	11.77
H_2O-	0.57	0.17	7.80	7.19
Total	99.84	99.69	99.25	99.36

[1] Bulk sample of welded ash-flow tuff collected from unit 3B at field trip Stop 1. Conventional rock analysis by E. M. Brandt, U.S. Geological Survey, Denver, Colorado.
[2] Separate of platy, bubble-wall glass shards from fresh vitric tuff collected 0.5 km northwest of field trip Stop 1. Conventional rock analysis by E. M. Brandt, U.S. Geological Survey, Denver, Colorado.
[3] Separate of chabazite from unit 2, field trip Stop 1 (from Gude and Sheppard, 1978).
[4] Separate of chabazite from unit 16, field trip Stop 1 (from Gude and Sheppard, 1978).

Table 2 shows chemical analyses of two chabazites and two fresh glasses. The chabazites were collected from units 2 and 16 in the measured section, and the welded-tuff specimen was taken from unit 3B. An airfall tuff from a site about 0.5 km northwest of the field trip stop is a typical platy, bubble-wall vitric tuff, with a

*(Continued on page 132, **Field trip**)*

SCENES FROM ANCIENT PORTLAND

Sketches of major events in the city's geologic history

by Larry G. Hanson, Department of Geology, Portland State University, P.O. Box 751, Portland, Oregon 97207

INTRODUCTION

The landscape of Portland owes much of its form to three major episodes of geologic events during the last few millions of years. The sketches attempt to go beyond conventional geologic description to portray these events as they might have appeared during those momentous times.

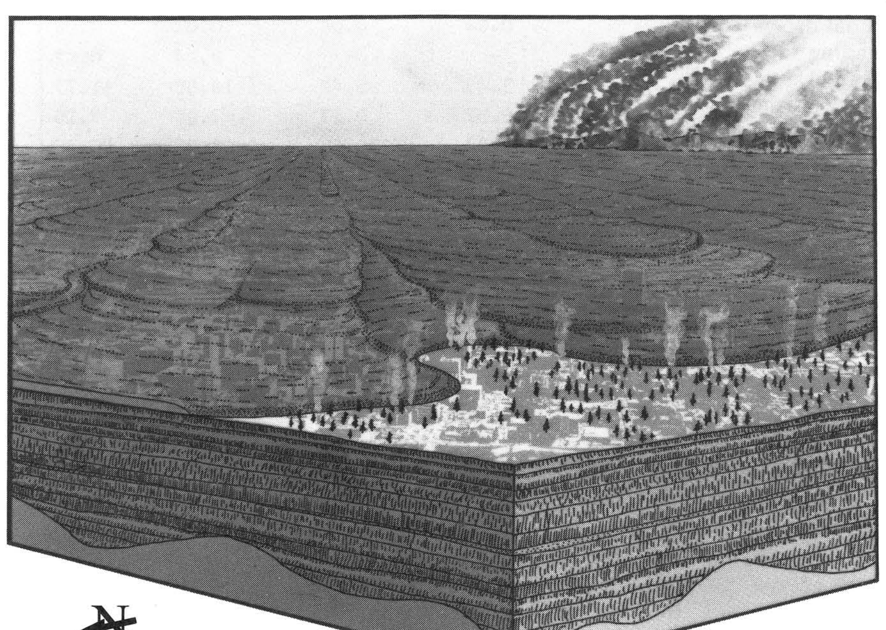
In each view, the drawing of the geologic event is superimposed on a photograph of the modern city to lend scale and relate the event to the present (in a "before/after" fashion). In the two older scenes, the modern city is intended to appear as a "ghost" of the future relative to the land-shaping event.

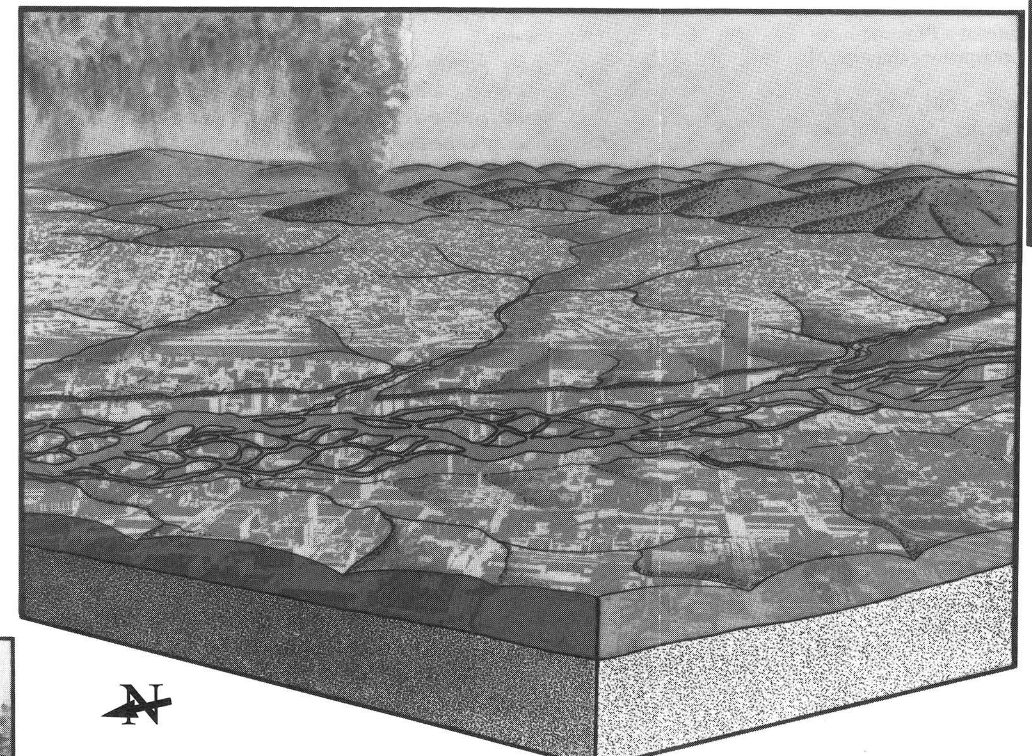
The author wishes to express his appreciation to John Allen, Marvin Beeson, and Paul Hammond, Portland State University, for their suggestions that helped guide this presentation. The photograph of Portland in 1974 is courtesy of the Oregon Historical Society.

16 MILLION YEARS AGO (below)

Lava of the remarkable flood volcanism spread across the city area (shown with the city image as a ghostlike background)

The lava was erupted from a long fissure, or crack in the ground, some 300 miles away in northeastern Oregon. The enormous volume and intense heat of this basaltic eruption enabled the lava to spread like molasses across this broad plain of the Northwest. The lava surged forth in vast lobes at speeds of up to 30 miles per hour. The rapid advance generally buried vegetation before it could ignite; however, in the foothills of the Cascades (background) along the flank of the lava field, forest fires raged. These mountains, with scattered volcanic peaks, were a subdued forerunner to the Cascades of today, and the flood basalt could spread across a wide tract in its westward course toward the sea. This was just one of more than a dozen flows that inundated the city area during this eruptive period. Thousands of years passed between some eruptions, and soils and vegetation developed on the tops of some of the flows. Although this scene was nearly flat, the Portland Hills formed a small anticlinal ridge (below and behind us) that diverted some of the flows. It was later that the major upwarp that lifted the hills to their present elevation was to occur. And similarly, it was after the event depicted in this scene that the flat volcanic layers shown here were bowed downward into a broad basin (the Portland syncline) that was then covered with ancient Columbia River gravels. This plain was to become the setting for the eruption of the Portland volcanoes shown in the next scene.

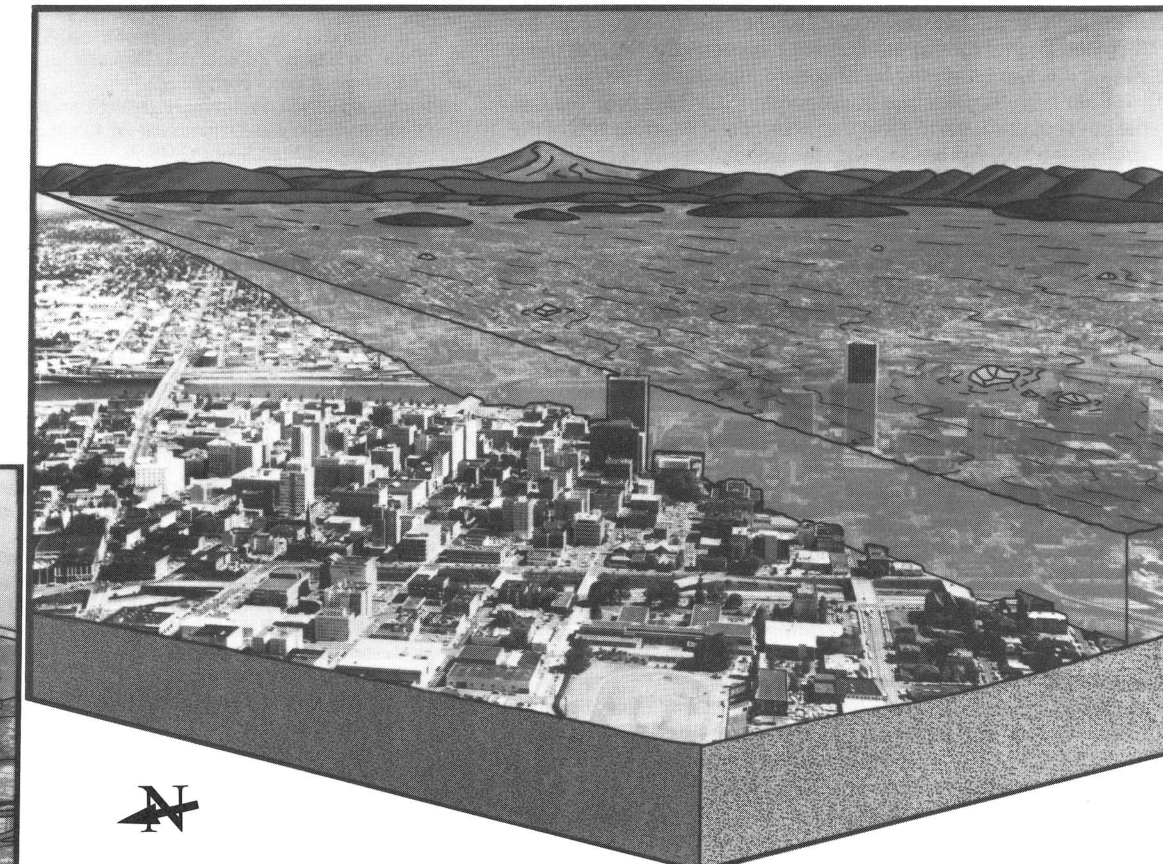




ONE MILLION YEARS AGO (?) (above)

An eruption of Mount Tabor scattered ash across the northeast Portland area (shown with the city image as a ghostlike background).

During the last few millions of years, Portland was the scene of hundreds of such eruptions. These nonviolent eruptions shaped the city area by building dozens of cinder and lava cones on the eroded surfaces of the more ancient plateau lavas and stream gravels. The hills of this city scene today represent extinct volcanoes or eroded remnants of volcanoes (such as Mount Tabor). Most of the volcanoes are cinder cones, although lava flows were erupted from the bases of many of them. The form of these volcanoes plus a few radiometric dates suggest that the oldest eruptions may have occurred several million years ago and the youngest, perhaps as recently as a few tens of thousands of years ago. The precise age of Mount Tabor, however, is undetermined. Collectively, the volcanic rocks produced during this eruptive period are mostly basaltic and are referred to by geologists as the Boring Lavas, named for the town of Boring where they were first described. They include numerous volcanic centers in the Portland Hills as well as south of the view area. The ancient landscape resembled the scene of today, although the exact location of the Willamette River at that time is not known; its location and nature as shown here are largely speculative.



14 THOUSAND YEARS AGO (above)

The Portland area was flooded by a catastrophic outburst from a glacial lake (shown in a cut-away section as it would have related to the modern city).

During the Ice Age, the site of Portland was swept by gigantic floods from the east. These were the immense "Spokane Floods," each of which resulted from the collapse of a glacier that had dammed a huge lake in Idaho-Montana (Glacial Lake Missoula). The released waters surged southwestward through the Columbia Gorge (upper left) to Portland. As indicated in the sketch, only tops of the higher buildings would have projected above the flood crest. Icebergs torn from the distant glaciers drifted across the flood surface. In the Portland area, the flood waters resembled a large turbulent lake that spread far to the south through the Willamette Valley. This flood endured for about two weeks and recurred roughly every century for more than a thousand years. The floods tore vigorously at the flanks of the volcanic hills and spread thick sheets of sand and gravel across the area to form a great "delta" — the upland plains of east Portland-Vancouver.

A LANDSCAPE MOLDED BY CATASTROPHE

The science of geology, in its quest to understand the patterns of earth evolution, has built its case on the principle of Uniformitarianism ("the present is the key to the past"). In the simplest of terms, this means that what we see at work on the land around us today represents the complex of processes that have worked to shape the land in the past. Although this principle has served the science admirably through the years, a rather unfortunate implication has strongly influenced its application. In this, the assumption has prevailed that the molding of most of the earth's surface has been governed by imperceptibly slow and sluggish processes (such as a creeping uplift of mountains and a grain-by-grain erosion of rivers), thereby taking thousands of years to produce significant changes in the landscape. More recently, however, the science has come to realize that the processes, such as the actions of streams, coastal waves, and tectonism, have frequently been so great that lands have been changed dramatically in mere days — in a "geologic instant." And so it is that geology is just beginning to recognize the importance of "catastrophe" within the concept of Uniformitarianism.

Although the 1980 eruption of Mount St. Helens is perhaps the most glaring demonstration of catastrophe in land shaping, virtually every piece of terrain in the Pacific Northwest has a heritage of geologic cataclysm built into its evolution. The site of Portland in the heart of the region is exemplary. Much of the modern land surface as well as the bedrock foundation and sediment blanket of greater Portland has been fashioned by cataclysms. The sketches are intended to depict three kinds of catastrophic events responsible for major changes in the Portland geologic history. It is hoped that these scenes will help geologists and nongeologists alike to better perceive events that are extreme and thereby difficult to comprehend. From this perhaps we can sense the remarkable magnitude and wonder of this awe-inspiring heritage. □

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(*Field trip, continued from page 129*)
texture similar to that seen in unit 16. The adsorption capacity for CO_2 and O_2 and the cation-exchange capacity for NH_4^+ of these chabazites were reported by Sheppard and Gude (1982).

Four scanning electron micrographs (SEM) are presented on the cover of this issue to show the textures and relationships of the zeolites with each other and with the associated authigenic smectite. SEM 1 (upper left) is an SEM from unit 3GY. The sample was taken from a cavity in a vertical fracture in the top of the welded tuff where the glass has been altered along the walls of the fracture. Radiating bundles of acicular erionite appear to have formed at the same time or shortly after the chabazite. The erionite coats some chabazite rhombs, but in the lower right corner of the SEM, the rhomb rests on the erionite. SEM 2 (upper right), an SEM of the tuff in unit 11, shows well-crystallized hexagonal rods of erionite present with clinoptilolite and more finely crystalline rhombs of chabazite. SEM 3 (lower left) is an SEM of material from a cavity in the tuff of unit 14B. Acicular erionite crystals have grown out into the cavity. Two size groups of chabazite crystals are visible; most are $<10\ \mu m$ on an edge, but some scattered rhombs are 15-20 μm in size. A few tabular clinoptilolite crystals are present with the chabazite. SEM 4 (lower right) is an SEM from unit 16 showing well-developed chabazite rhombs on a mat of fine-grained clay. Several of the chabazite crystals are interpenetrating twins on (0001).

ZEOLITE DIAGENESIS

The Pliocene Durkee basin is an example of a "closed-basin" zeolite deposit. A depositional environment existed in a constricted 18-20 km^2 pond at the south end of the valley when the outlet was dammed to form a shallow soda lake. Rapid deposition of siliceous vitric tuffs into the highly saline, alkaline water provided the kinetic and geochemical conditions required for a low-temperature, low-pressure diagenesis to alter the tuffaceous material to zeolites. Table 3 shows the paragenetic zeolite sequence established from optical and scanning electron microscopy and X-ray diffraction analysis.

Table 3. Paragenesis of authigenic minerals at the Durkee, Oregon, zeolite deposit.[1]

Glass, then:				
Phillipsite	-->	Clinoptilolite + Erionite		
Phillipsite	-->	Erionite		
Smectite	-->	Clinoptilolite		
Smectite	-->	Chabazite	-->	Clinoptilolite
Smectite	-->	Phillipsite	-->	Clinoptilolite
Smectite	-->	Erionite	-->	Clinoptilolite
Smectite	-->	Chabazite	-->	Erionite
Phillipsite	-->	Clinoptilolite		
Phillipsite	-->	Erionite + Chabazite		
Any of the above zeolites (but not glass or clay)	-->	Analcime + Potassium Feldspar		

[1]Adapted from Gude and Sheppard (1978).

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Governor creates Oregon Land Information Advisory Committee

A new Oregon Land Information Advisory Committee has been created by Governor Victor Atiyeh. Its goal, according to Kenneth J. Dueker, Committee Chair, is to help the State avoid the threat of seriously incompatible and duplicative land information data, caused by the increasing computerization of geographic mapping and inventory systems in Oregon State agencies, local governments, and public utilities.

Dueker, Director of the Center for Urban Studies in the School of Urban and Public Affairs at Portland State University, noted that the new committee will draw on the recent success of an interagency Strategic Water Management Group, which cooperated to share land and water data while building a new geographic information system for the John Day River Basin.

If the new committee can successfully promote data compatibility and sharing of information among the diverse entities across Oregon, Dueker predicted that "... this will lead to more timely and accurate answers to land information questions at all levels of government."

Governor Atiyeh also directed that three subcommittees be established to help the new committee carry out its work: a Standards and Base Mapping Subcommittee chaired by Deputy State Geologist John Beaulieu, Oregon Department of Geology and Mineral Industries; a Project Coordination and Technical Issues Subcommittee chaired by Gary Waltenbaugh, Manager of Special Programs, Oregon Department of Energy; and a Land Records Subcommittee chaired by Dueker. □

Mining in wilderness

by Daniel G. Avery, Area Mining Geologist, Wallowa-Whitman National Forest, Baker, Oregon

THE LAW

The General Mining Laws give a United States citizen the right to locate mining claims upon unreserved public domain lands, including the National Forests, to explore for or extract minerals. Although the Mining Laws have been supplemented and amended over the years, many of the key provisions remain intact. The general procedure for locating and holding mining claims involves (1) making a discovery of a valuable locatable mineral deposit (excluding leasables such as oil, gas, coal, phosphate, and sodium and salables such as common varieties of sand, gravel, and cinders); (2) recording the claim in the appropriate county courthouse and state office of the Bureau of Land Managment; and (3) performing at least $100 worth of annual assessment work for development of the mineral deposit on the claim.

Through this process, any number of claims may be located, subject to the following limitations: Lode claims (claims on minerals in solid rock), each with maximum dimensions of 600 by 1,500 ft or approximately 20 acres; and placer claims (generally, claims on heavy-mineral deposits concentrated in gravel), also limited to 20 acres. These per-person limits may be used by maximally eight individuals in association so that a single claim may be as large as 160 acres. No approval is required from the government to locate these claims, and no royalty payments are made for minerals produced from them.

The National Wilderness and Preservation Act of 1964 was passed to preserve and protect lands in a natural condition for present and future generations. As stated in the Act, "A wilderness, in contrast with those areas where man and his works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." Several criteria were given to further define wilderness. The areas were to be undeveloped Federal land retaining "primeval character and influence" and without permanent improvements or human habitation. The areas were to be primarily affected by nature, with human work substantially unnoticeable; they were to provide outstanding opportunities for solitude, or primitive, unconfined recreation; they should be 5,000 acres or larger, or of sufficient size for practical use and preservation in an unimpaired condition; and they could contain ecological, geological, or other features of scientific, educational, scenic, or historic value.

However, under the Act, entry under the Mining and Mineral Leasing Laws was to continue within the wildernesses created by the Act until December 31, 1983. Both the Wilderness Act and the subsequently enacted USDA Forest Service surface-use regulations allowed for mining activities to continue, with a goal of maintaining an unimpaired Wilderness Preservation System. This unimpaired condition was to remain while allowing location, exploration, development, and production of mineral deposits. Permitted activities could include construction of necessary water and power lines and use of mechanized transport and motorized equipment. Also, the U.S. Geological Survey and the U.S. Bureau of Mines were directed to conduct mineral studies of the areas. By keeping them open to mineral exploration and development by private industry for a period of 20 years, and by simultaneously conducting Federal mineral investigations, it was hoped that these lands would not be closed to development without a reasonably accurate knowledge of their mineral potential.

This apparent conflict between unimpaired wilderness preservation and allowance for mineral development was the result of a compromise reached between the Senate and the House of Representatives. The original House version of the Wilderness Bill provided for a 25-year period in which the Mining and Mineral Leasing Laws would continue to operate, while the original Senate version provided for immediate withdrawal. The compromise, which became the Wilderness Act of 1964, remained closer to the House version, providing for a 20-year period of operation under the Mining and Mineral Leasing Laws.

The General Mining Laws gave the public the right to enter the lands belonging to the United States, including the wildernesses through December 31, 1983, and the right to prospect for and mine valuable mineral deposits. In actual practice, many mining companies and individual prospectors appeared to be reluctant to pursue mineral exploration under the more rigid environmental constraints imposed on operations within wilderness. Additional perceived constraints were the general public sentiment against mineral development within wilderness and the question of whether development of a major mineral deposit would be allowed to take place. Given these factors, the major companies tended to ignore all but the most attractive targets within wilderness.

Critics have suggested that government studies of the mineral potential of wildernesses were limited by time, manpower, and funding. The inventories were to cover not only the areas created by the 1964 Act but also areas subsequently added to the system and areas recommended for wilderness or further study under the Forest Service Roadless Area Review (RARE and RARE II) processes. Since minerals are generally a hidden resource, it was not feasible to make a thorough evaluation of the mineral potential of much of the land under consideration.

VALID CLAIMS

The State of Oregon now has a total of 35 wildernesses, covering over two million acres. All 13 National Forests have at least one wilderness, and one Forest has eight. Most of these wildernesses were established by the 1964 act and automatically became closed to mineral entry on December 31, 1983. On June 26, 1984, the Oregon Wilderness Act of 1984 was signed by the President. The 849,300 acres of new wilderness established by this Act were added after the December 31, 1983, closure to mineral entry specified by the 1964 Act and were therefore instantly withdrawn. Included within the new additions to wilderness were well over a thousand mining claims, whose owners had not been operating under wilderness regulations. Holders of claims in the older wildernesses knew, or should have known, that their claims would have to be valid as of the December 31, 1983, closure in order to establish a right to any locatable minerals within the claim boundaries. Claimants in the new wildernesses may have been caught by surprise with the instant withdrawal from mineral entry and attendant requirement for validity.

In order for a claim to be valid, a claimant must (1) discover a valuable mineral deposit, (2) post the discovery on the ground, (3) do the discovery work (not required in Oregon), (4) monument the claim on the ground as required by State and Federal laws, (5) record the claim at the appropriate county courthouse, and (6) within 90 days of location, file a copy of the recorded claim notice with the state office of the Bureau of Land Management. Very often, the first element of validity is missing. The definition of a valid discovery was first made in 1894 in the case of *Castle* v. *Womble*, 19 LD 455 (1894), in which the Secretary of the Interior stated:

"... where minerals have been found and the evidence is of such a character that a person of ordinary prudence would be justified in the further expenditure of his labor and means, with a reasonable prospect of success, in developing a valuable mine, the requirements of the statutes have been met."

This definition, known as the "prudent person test," has since been reaffirmed in numerous cases before the Supreme Court of the United States and has withstood the test of time. In practice, this means that in order to be valid, a claim must show a mineral deposit which can be demonstrated to have a reasonable chance of being mined at a profit, based on current knowledge of the character of the deposit and the market condition available for the mineral to be extracted. A recent administrative decision [*In re Pacific Coast Molybdenum Co.*, 75 IBLA 16 (1983)] found that during depressed economic conditions, immediate profitability need not be shown. However, a potential for profit must exist given recent historic price/cost figures and reasonable expectations for a return to more normal market conditions.

It is common practice to locate a mining claim on the ground prior to making an actual discovery of a valuable mineral, as required under the General Mining Laws. As long as the locator physically occupies such a claim, excludes rival claimants, and diligently makes a good faith effort to perfect a discovery, he is protected from rival claimants by the doctrine of *Pedis Possessio*, or "foot-hold." However, he is given no rights against the government until a discovery is perfected. Many of the claims within the 1984 wilderness additions may not have discoveries, partly because the claimants had been operating in land open to the General Mining Laws and were not facing a definite date at which a discovery had to be made. Such claims will have acquired no rights against the government to minerals in the ground.

Validity will be determined by physical and economic conditions prevalent leading up to the date of the withdrawal. A discovery must have been present on the withdrawal date, and the possibility for extraction of minerals from the claim at a profit must be shown to have been reasonably likely. This precludes consideration of any subsequent radical price increases for mineral commodities that may take place after the withdrawal date. No work done after this date may be used to establish a discovery. Only existing surface exposures, verifiable drilling data, cuts, shafts, and adits may be considered in the validity process. Professionally prepared reports and analyses on the subject claim(s) dealing with quantity and quality of mineral to be extracted, along with records or estimates of production and recovery costs, will be extremely helpful to the claimant wishing to establish validity.

The rights accompanying a claim within wilderness depend upon the status of the land at the time of its location. Valid claims located on land prior to inclusion within the Wilderness System are under the General Mining Laws that were applicable to the land at the time. Claims located subsequent to wilderness designation and prior to withdrawal from mineral entry are under the General Mining Laws *and* the establishing legislation for the wilderness. One of the main differences between the two situations pertains to claims that are taken to patent (private ownership). All valid preexisting claims located in wildernesses that have been created after the December 31, 1983, closure date (such as the areas included within the 1984 Oregon Wilderness Act) and any claims validly established prior to the inclusion in the Wilderness System of the land on which they are located may be taken to full private ownership (mineral and surface estate). A claim that was located within an existing wilderness and validated prior to withdrawal from mineral entry may be patented only for its mineral estate. The surface remains with the Federal Government, subject to the rights of the claimant to the use of as much of the surface estate as is necessary to exercise his/her right to the minerals. Once validity is established, the claimant has a property right that cannot be extinguished without payment of just compensation.

Access to valid mining claims wholly within wilderness is to be permitted "by means consistent with the preservation of the National Forest Wilderness which have been or are being customarily used with respect to other such claims surrounded by National Forest Wilderness" [Code of Federal Regulations — 36 CFR 228.15 (c)]. This direction gives the Authorized Officer maximum latitude to determine what will be allowed. In practice, access is considered in relation to the need of the claimant. Requests for access may take into consideration (among other things) the claimant's proposal, distance from wilderness boundary, difficulty of terrain, impact on wilderness values, weight and complexity of materials to be transported, and existing access routes.

CONCLUSION

Mining in wilderness, a touchy subject during the 20-year period during which the General Mining Laws applied, may be even more controversial now that the date of withdrawal has passed. The administrative guidelines for handling mining proposals on those claims which prove to be valid, by necessity, leave room for interpretation. Efforts must be made to find creative solutions for developing a balance between the miners' desires to operate and the goal of preventing degradation of the National Forest wilderness environment.

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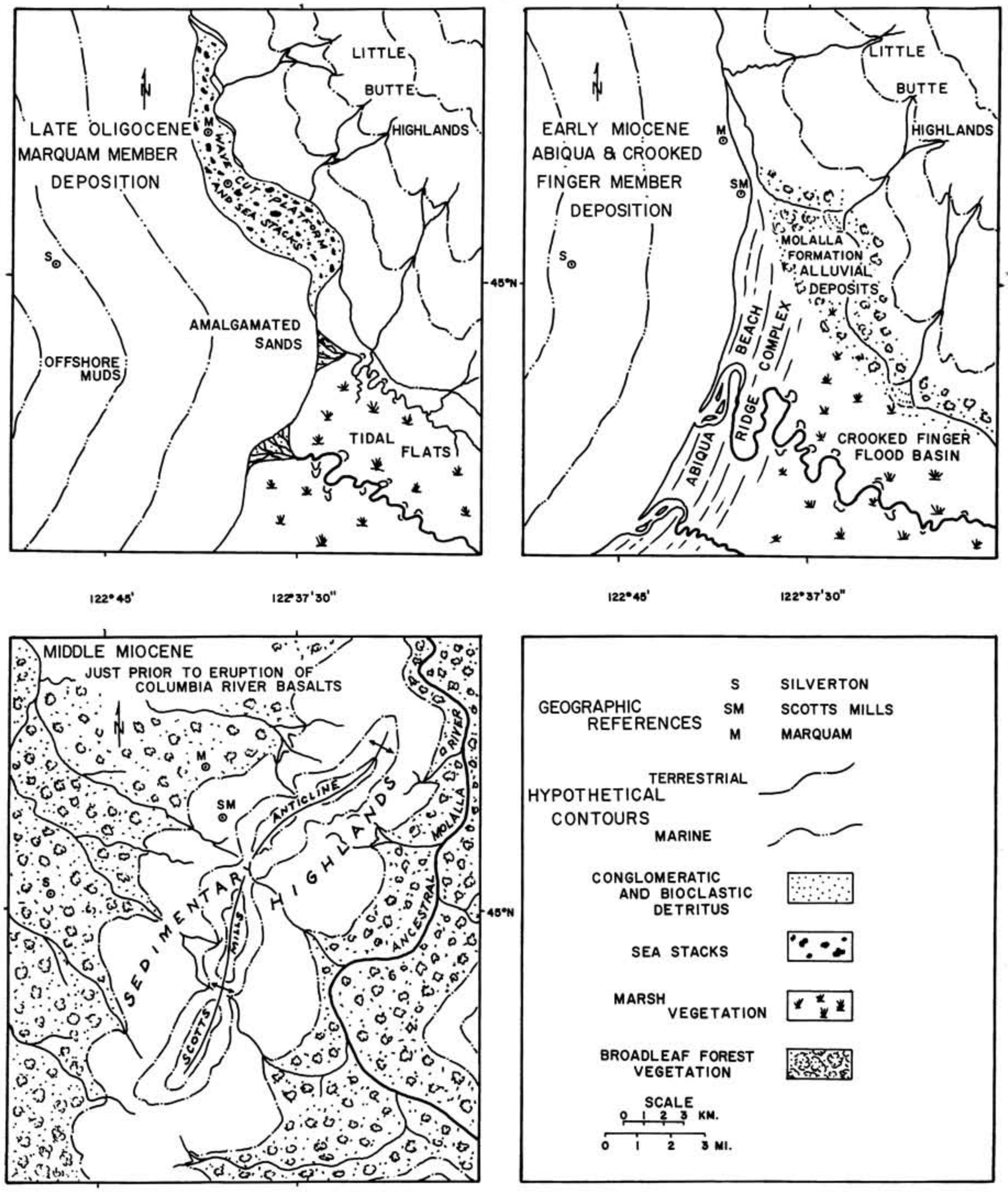

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of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

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

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

COVER ILLUSTRATION

Paleogeography of area near Scotts Mills, Marion County, location of Scotts Mills Formation described in article beginning on next page. Upper left, Marquam Member paleogeography, late Oligocene; upper right, paleogeography during deposition of Abiqua and Crooked Finger Members and lower Malalla Formation strata, early Miocene; lower left, paleogeography just prior to eruption of Columbia River basalts, middle Miocene.

OIL AND GAS NEWS

Mist Gas Field

ARCO Oil and Gas Company has completed its 1986 drilling program. The Cavenham Forest Industries well 41-9 and a redrill of 41-9, located in sec. 9, T. 5 N., R. 4 W., were drilled to 2,500 and 2,501 ft, respectively, and were plugged and abandoned. The final well, Columbia County 31-8, located in sec. 8, T. 6 N., R. 5 W., was drilled to 4,054 ft and plugged. The results of ARCO's summer drilling were two successful completions, five dry holes, and two dry redrills.

Tenneco Oil Company spudded Columbia County 24-28, located in sec. 28, T. 6 N., R. 5 W., on November 6. Permit depth is 3,500 ft.

Willamette Valley wildcat spuds

On October 17, Damon Petroleum Corporation, Inc., commenced drilling Stauffer Farms 35-1, located in sec. 35, T. 4 S., R. 1 W., Marion County, a few miles east of Hubbard. Permit depth is 2,800 ft. □

Geologic map added to Oregon offshore maps

The Oregon Department of Geology and Mineral Industries (DOGAMI) announces the publication of a new geologic map of the ocean floor off Oregon. The new release, *Geologic Map of the Ocean Floor Off Oregon and the Adjacent Continental Margin,* has been published as Map GMS-42 in DOGAMI's Geological Map Series.

With the release of GMS-42, DOGAMI has added a comprehensive geologic map to the continuing exploration of Oregon's offshore areas including the Exclusive Economic Zone proclaimed in 1983. This map was preceded by a mineral resources map (DOGAMI GMS-37) and a bibliography and index map (DOGAMI GMS-39). All three maps were produced through the joint efforts of the U.S. Minerals Management Service, the College of Oceanography of Oregon State University, and DOGAMI.

The new geologic map was compiled from a large number of published and unpublished data by C.P. Peterson and L.D. Kulm, both Oregon State University, and J.J. Gray, DOGAMI. The full-color map is approximately 3½ by 5 feet in size (scale 1:500,000) — and depicts the structure and over 60 different rock units of the ocean floor, continental slope, continental shelf, and adjacent onshore areas for the entire north-south extension of the Oregon coast. The map is accompanied by a four-page explanatory text.

The new geologic map is now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201. The purchase price is $8. Orders under $50 require prepayment. □

To our readers

Due to the length of this month's geologic paper, we are unable to print the usual list of available publications. We regret this restriction of your ordering convenience but assure you that the list can be mailed to you upon request. Write to the Department address, attention business office, or phone (503) 229-5580.

Reminder to renew! Since many of you may wish to renew this month, we left the renewal form in its usual place. However, if you wish to save the annual index, please use only a photocopy of the last page for renewing.

— *The editors*

The Scotts Mills Formation: Mid-Tertiary geologic history and paleogeography of the central Western Cascade Range, Oregon

by Paul R. Miller and William N. Orr, Department of Geology, University of Oregon, Eugene, Oregon 97403*

ABSTRACT

The name Scotts Mills Formation is proposed for a mid-Tertiary marginal marine sequence exposed along the central Western Cascades of Oregon. Three members are recognized. The basal Marquam Member, over 500 meters (m) thick, was deposited along a rockbound volcanic coastline during the late Oligocene. The Marquam Member is medium- to dark-gray or bluish-gray volcanic arenite and is locally highly fossiliferous. The 250-m-thick Abiqua Member is buff-tan tuffaceous arkose deposited by beach ridge accretion. The uppermost Crooked Finger Member is up to 200 m thick and represents swampy lowlands landward of the Abiqua beach ridge system. The Crooked Finger Member is olive-gray immature volcanic arenite with interbedded coals. The two uppermost Scotts Mills members interfinger with tuffaceous strata at the base of the Molalla Formation. During the early to middle Miocene, gentle folding occurred along the Scotts Mills anticline, and considerable erosional relief developed prior to the incursion of Columbia River basalt flows into the area. Subsequent erosion produced the inverted volcanic topography that characterizes the area today. Field relationships suggest that the latter half of the Oligocene was a period of tectonic quiescence along the ancestral Cascades. These relationships provide independent support of the two-phase model of tectonic rotation proposed by Magill and Cox (1981).

INTRODUCTION

Tertiary tectonic movement of the Oregon Western Cascades and associated crustal blocks in the Pacific Northwest has been the subject of much attention over the past several years (e.g., Simpson and Cox, 1977; Magill and Cox, 1981; and Bates and others, 1981). At the same time, sedimentary units in the Cascades have received comparatively little attention. Recent work by Miller (1984), Miller and Orr (1983a,b,c; 1984a,b), Orr and Miller (1982a,b; 1983a,b,c; 1984; 1986a,b), and Linder and others (1983) has focused almost solely on this area.

This paper describes sedimentary lithostratigraphic units exposed along the westernmost flanks of Oregon's central Western Cascade Range (Figure 1) and supplements recent geological mapping in the area (Miller and Orr, 1984a,b; and Orr and Miller, 1984; 1986a,b). Additionally, a formal nomenclature is proposed for marginal marine and terrestrial sedimentary rocks deposited along the ancestral Cascade Arc. The field relationships discussed here provide independent evidence of geologic events occurring during the tectonically pivotal late Oligocene-early Miocene interval. Prior to this study, the timing of tectonic rotational events was inferred from paleomagnetic data.

The name Scotts Mills Formation is proposed for a 1,000-m-thick sequence of volcaniclastic sediments deposited along the western margin of the ancestral Cascades in the late Oligocene/early Miocene interval. The formation is divided into three members. In ascending order, these are the Marquam, Abiqua, and Crooked Finger Members. Additionally, the Molalla Formation is revised, and new reference sections are designated. The areal distribution of these units is shown on Figure 2 and on soon-to-be released geologic maps of the Drake Crossing and Elk Prairie 7½-minute quadrangle maps (Orr and Miller, 1986a,b).

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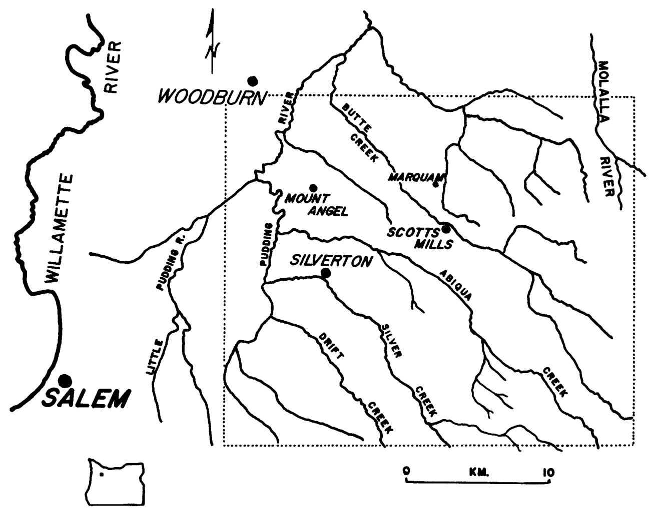

Figure 1. Map of study area.

The study area covers some 500 square kilometers (km^2) lying 10 km east of Salem, Oregon. The most extensive exposures of sedimentary rock are in the vicinity of Scotts Mills, Oregon. These rocks disappear under Neogene volcanic flows to the south. Well-developed soils and lush vegetation characterize the area and restrict natural bedrock exposures to the canyons of northwest-trending streams draining the Western Cascades.

PREVIOUS WORK

Most of the rocks assigned here to the Scotts Mills Formation were referred to informally as the "Butte Creek beds" by Harper (1946). Peck and others (1964) mapped these rocks along with those of the Eugene Formation as "Tertiary marine rocks." Hampton (1972) followed the designation of Peck and others (1964) and described the unit as "marine tuffaceous sandstone and sandstone."

The lithologically similar Scotts Mills and Eugene Formations are of markedly different ages. Presently, the Eugene is assigned to the upper Eocene (Armentrout and others, 1983), whereas the Scotts Mills is of latest Oligocene age (Miller and Orr, this paper).

Durham and others (1942) assigned an early Miocene (Vaqueros) age to a diverse marine fauna preserved near the base of the Scotts Mills Formation. This was based on the presence of *Pecten sespeensis* Durham, in addition to the pelecypod taxa *Spisula albaria* Conrad, *Spisula* cf. *catilliformus* Conrad, and *Tellinga oregonensis* Conrad. Durham and others noted that these marine sediments interfinger to the east with terrestrial sediments bearing a lowermost Miocene flora.

Peck and others (1964) and later Hampton (1972) described the Oligocene and Miocene Little Butte Volcanic Series of Wells (1956) in two parts. Nonmarine pyroclastic strata of the upper Little Butte were found to interfinger with sediments of Harper's (1946) "Butte Creek beds."

The base of the Little Butte consists of basaltic flows, tuffs, and breccias. Harper (1946) mapped the basalts as "pre-Butte Creek lavas" and assigned a questionable Eocene age to the unit. More than 100 m of erosional relief developed on the Little Butte

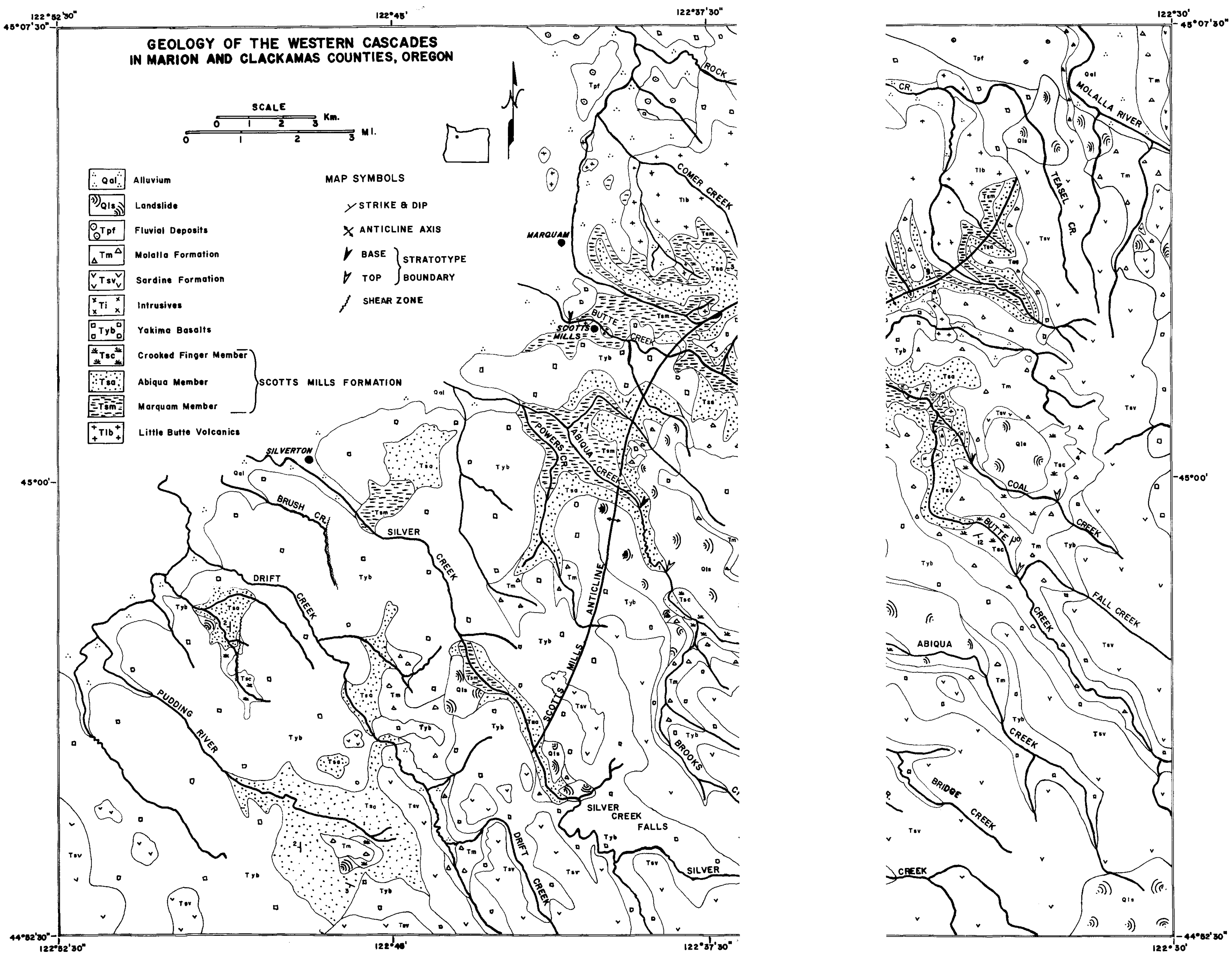

Figure 2. Geologic map of the Scotts Mills inlier.

basalt surface prior to Scotts Mills and Molalla Formation deposition (Miller, 1984).

The Scotts Mills Formation is unconformably overlain by basalt of the Columbia River Basalt Group and by Miocene and younger andesitic rocks of the Sardine Formation (Thayer, 1939). These stratigraphic relationships are summarized in Figure 3.

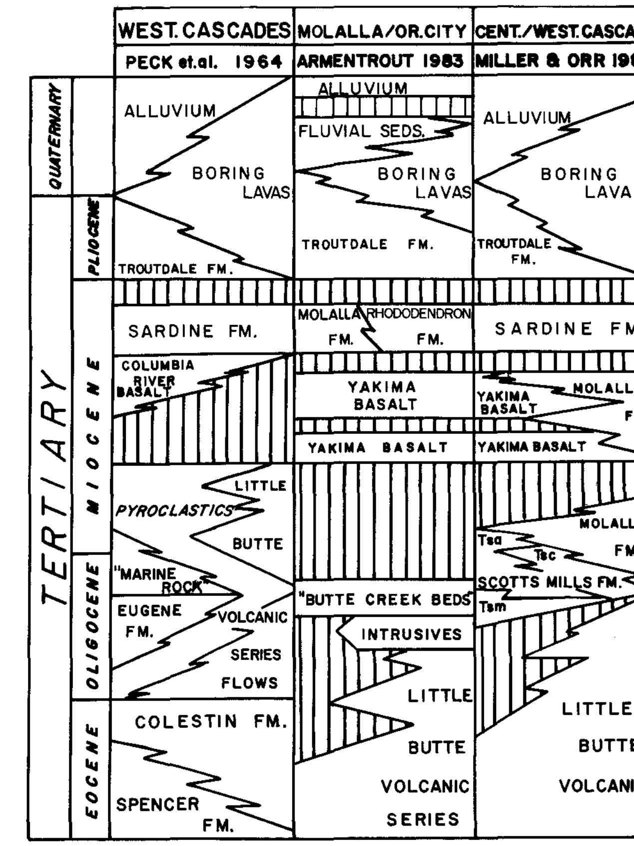

Figure 3. Correlation chart for the central Western Cascades.

STRUCTURE

Mid-Tertiary strata are exposed in the study area along the Scotts Mills inlier (Figure 2). Deposits of the Scotts Mills and Molalla Formations are gently upwarped with average dips of less than 10°. The Scotts Mills anticlinal axis strikes northeast-southwest and parallels the Sardine syncline and Mehama and Breitenbush anticlines to the east and the Willamette syncline to the west. Closure of the fold is indeterminate but must be on the order of several hundred meters.

At the core of the inlier, flows of Columbia River basalt filled deeply incised stream valleys cut into the anticline during uplift. These intracanyon flows cast the ancient drainage network in stone, and subsequent erosion has selectively removed the less resistant sedimentary rocks to yield an inverted volcanic topography. The modern, pronounced, northwest-trending drainage systems in the area are controlled by these inherited structural trends (see Figure 1).

SCOTTS MILLS FORMATION

Rocks assigned to the Scotts Mills Formation include those mapped by Harper (1946) as the "Butte Creek beds," and portions of those mapped as "marine rocks" by Peck and others (1964) and Hampton (1972).

The unit stratotype for the Scotts Mills Formation is along Butte Creek between the 360- and 1,000-ft elevations. Just above Scotts Mills, the sedimentary section is interrupted by Columbia River basalt flows. Sedimentary rocks here record deposition in marine inner neritic to terrestrial environments and represent more than 16 km^2 of nearly continuous outcrops. All three of the Scotts Mills members are exposed along the Butte Creek section. Measurements of the Scotts Mills stratotype and correlative member reference sections appear in Figure 4.

Marquam Member

The lowermost and most environmentally diverse of the Scotts Mills members is the Marquam Member. The unit is named for exposures south of the community of Marquam, Oregon. The section stratotype is along Butte Creek, between the 360- and 720-ft elevations.

The wedge-shaped Marquam Member pinches out against the Little Butte basalt to the north of the study area (Figure 5).

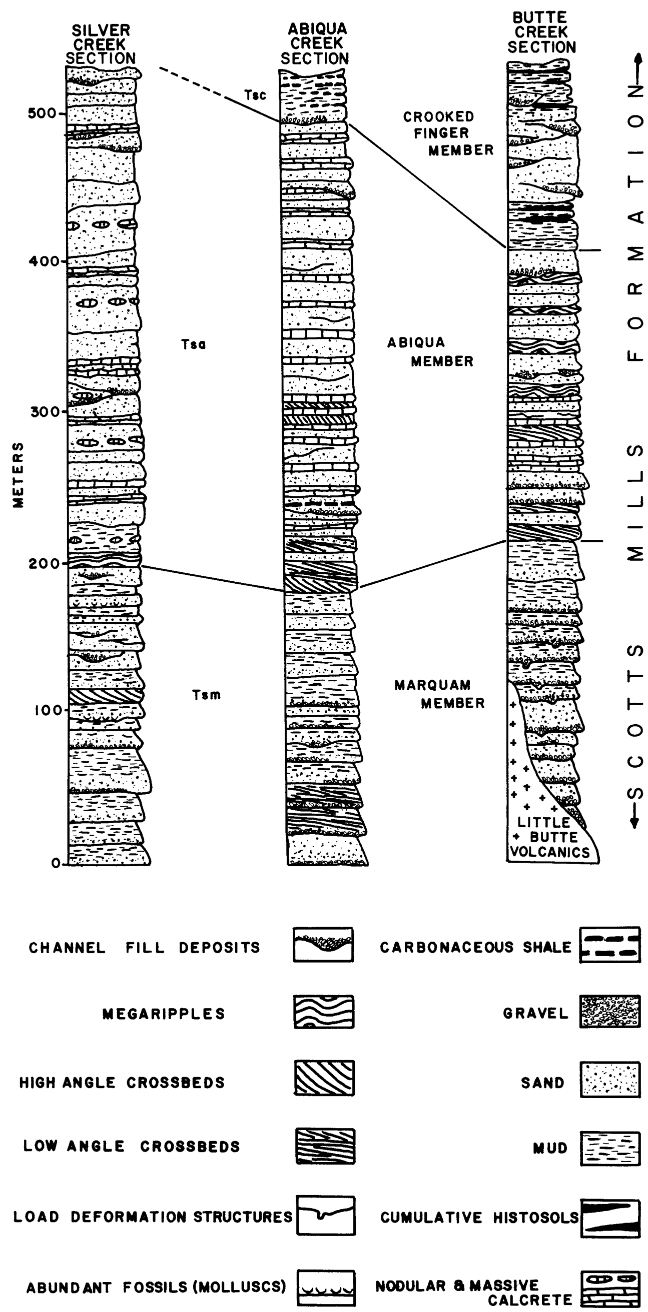

Figure 4. Measured composite stratigraphic sections from the valleys of Butte, Abiqua, and Silver Creeks. Sections include unit stratotypes and reference sections for the Scotts Mills Formation and constituent members.

More than 300 m of Marquam sediments are exposed, and a drill hole in the area penetrated a 600-m section. The best exposures of the unit are in the deeply incised valleys of Butte and Abiqua Creeks. Upland areas underlain by the Marquam Member commonly host a thick colluvial and vegetative cover. Locally, erosion of the unit develops a hummocky topography.

Lithology and distribution: Weathered Marquam sediments are light to medium gray, and fresh samples are a characteristic bluish gray. Conglomeratic intervals assume the dark-gray to black color of the constituent basaltic clasts. Near its base, the member is abundantly fossiliferous. Miller (1984) and Miller and Orr (in press) have recognized several depositional facies within the Marquam, related to the erosional topography of the underlying Little Butte basalt surface.

Conglomeratic detritus and shallow-water epilithic faunas characterize sediments near the contact of the Marquam with the underlying Little Butte basalt. *Mytilus* (mussel) channel lag accumulations and cirriped (barnacle)-rich megaripple cross beds (Figure 6a) are characteristic of sediments onlapping the basalt high in the northern part of the study area. The distribution of these features with respect to the Little Butte erosional surface and the more basinward Marquam facies delineates an ancient headland flanked by progressively deeper marine water to the southwest and west.

Exhumed wave-cut platforms and sea stacks developed on the Little Butte basalt are common along Butte Creek (Figure 6b). These features were separated from the northern headland during Marquam sedimentation and are characterized by steep slopes surrounded by conglomeratic and bioclastic debris. The winding course of Butte Creek developed as stream incision sidestepped the erosionally resistant exhumed basalt features in favor of the more easily eroded onlapping sediments.

Basinward of the exhumed shoal exposures, sandstones form steep cliffs along the valleys of Butte, Abiqua, and Silver Creeks (Figure 6c). These outcrops are comprised of sandstone beds less than a meter thick, annealed during storm-related resedimentation. Sandstone sequences here are commonly more than 15 m thick, and sharply truncated upper bounding surfaces typically mark the top of the interval. Lensoid concentrations of mud-filled, articulated pelecypods *Acila* and *Spisula* are common along the scoured bases of annealed strata. The deposits have yielded the remains of the mid-Tertiary cetacean *Aetiocetus* (Orr and Faulhaber, 1975; Orr and Miller, 1983a) and the trace fossil *Cylindrichnus* (Orr and Miller, 1983c).

Amalgamated sand sheets commonly give way upward and distally to thin-bedded, graded units comprised of simple sand-clay couplets. The individual graded units are as thin as 5 cm. Claystones are cross-stratified, and the underlying mud or sandstones show a weakly discernible parallel lamination.

Near the top of the member, tidally deposited sandstones and tuffaceous argillites are common. These deposits consist of flaser, wavy bedded, and micro-cross-laminated accumulations of volcanic ash, finely disseminated organic matter, and basaltic detritus. Tidal deposits here are thoroughly burrowed, and richly tuffaceous portions bear an abundance of carbonized leaves, wood fragments, and reedy plant remains.

Petrography: Sedimentary deposits of the Marquam Member consist of a mixture of basaltic rock fragments and bioclastic detritus. Lesser components include unstable mineral glasses and calcic plagioclase feldspars. Basaltic clasts in these deposits display all degrees of alteration, from fresh to almost completely decomposed.

Barnacle plate fragments are common in association with conglomeratic sediments and syndepositional exposures of Little Butte basalt. The plate-shaped fragments facilitate the development of shelter porosity in cirriped-rich deposits cemented with carbonate and later silica cements. Typical Marquam sandstone is shown in Figure 6d.

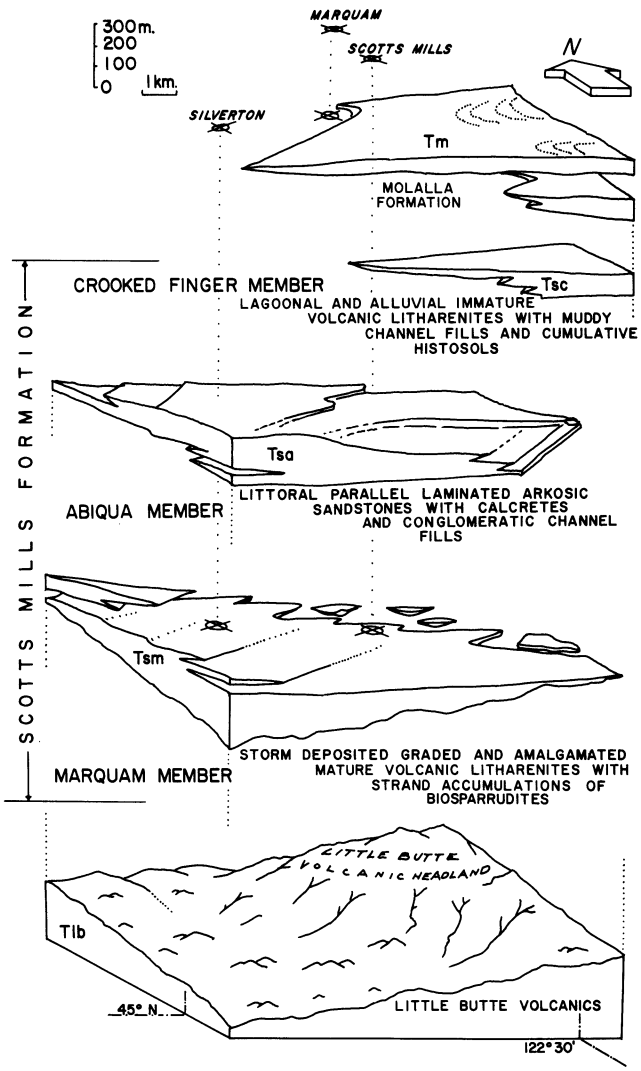

Figure 5. Drawings showing generalized geometries of mid-Tertiary geologic units exposed in the central Western Cascades of Oregon. See text for discussion.

Facies interpretation: During the late Oligocene, locally derived basaltic detritus was deposited as volcanic flows of the early Cascade Arc were transgressively inundated. Throughout Marquam deposition, the Little Butte basalt formed a headland with a deep marine embayment to the southwest. Erosional features including sea stacks and wave-cut platforms were cut along rockbound stretches of the coastline, while tidal flats were developed in the absence of contemporaneous bedrock exposures. During storm events, sediments were eroded from these nearshore areas and transported offshore.

Many of the characteristics of storm deposits described over the past several years (e.g., Brenner and Davies, 1973; Kumar and Sanders, 1976; and Kreisa, 1981) can be recognized within the Marquam. These include extensive scouring, erosion, and resedimentation of previously deposited sediments, as well as very rapid depositional episodes punctuated by longer periods of limited deposition.

Storm-dominated sedimentation was the primary mechanism governing Marquam deposition. Sediments of the Marquam were derived as the geomorphologically stable Little Butte surface was drowned by transgressive marine waters. On the basis of modern analogs, soils and coastal terraces undoubtedly mantled the bedrock surface. During transgression, these unconsolidated deposits were subjected to progressive wave erosion and ultimately redeposited offshore. Unlike the younger units described below, the Marquam was deposited as the ancestral Cascades passively underwent marine transgression in the absence of significant tectonic or magmatic activity.

Abiqua Member

The Abiqua Member overlies deposits of the Marquam Member and includes over 250 m of tuffaceous and arkosic sandstones and gravel conglomerates. The lens-shaped unit is elongated parallel to the northeast-trending anticlinal axis. Physiographically, Abiqua exposures are characterized by deep canyons and low, dome-shaped hills in upland areas.

The unit stratotype is along Abiqua Creek 9 km southeast of the intersection of Abiqua Road and Highway 213 in the northwest corner of sec. 11, T. 7 S., R. 1 E., just upstream of the Abiqua Road bridge over the creek. A reference section is designated along Butte Creek between the 720- and 880-ft elevations.

Lithology and distribution: The Abiqua weathers to a reddish, light-buff to tan color on exposed lowland surfaces but is locally bleached to a brilliant white in cliffs. Deposits tend to be well indurated. Fresh exposures may take on a bluish hue but more often differ from their more weathered counterparts only on the basis of a lesser degree of iron oxide mineralization.

Most of the sequence is sandy, although small, gravel-filled channel deposits are scattered throughout the section. In the upper part of the member, mud-filled channels bearing Teredo-bored wood transect the earlier sandy deposits.

Characteristic primary sedimentary structures in the Abiqua Member are parallel and low-angle cross-stratification (Figure 7) (the swash cross-stratification of Wunderlich, 1972). Structureless beds become increasingly common at the top of the section in association with the Molalla Formation.

Basal strata of the member exposed in T. 6 S., Rs. 1 and 2 E., are richly fossiliferous. These consist of vertically repetitive sequences of storm-deposited swell lag concentrates (of Brenner and Davies, 1973) in association with massive or graded tuffaceous sands. Invertebrates recovered from this locality include species of the gastropods *Bruclarkia, Acmaea,* and *Echinophoria* and the pelecypod *Chlamys.* In addition, shark teeth and arthropod fragments have been recovered.

South of the boundary of Ts. 6 and 7 S., Abiqua Member sandstones are transected by thin continuous horizons of the concretionary carbonate (Figure 7b). These discordant features are dark-reddish brown or dark-gray and are superimposed over earlier primary sedimentary structures. Diagenetic carbonates here are sheetlike and subparallel to the overlying disconformity. These carbonate horizons are on the order of 10 cm thick and are remarkably uniform throughout the area. Semeniuk and Meagher (1981) termed analogous modern features nonpedogenic calcretes and attributed their formation to the seasonal evapotranspiration regime of southwestern Australia.

Petrography: The appearance of extrabasinal detritus including polycrystalline quartz, muscovite, and granitic or metamorphic rock fragments reflects a strong shift in provenance compared to the underlying Marquam Member. The appearance of these exotic sediments accompanies the introduction of large amounts of volcanic ash into the marine environment. Tuffaceous volcanic arkoses of the Abiqua Member are submature to mature in texture and composition and are characterized by simple cementational histories. Corrosive silica cements follow earlier generations of carbonate cements in Abiqua deposits and are of opaline character. Opaline silica was derived from the solution of unstable mineral glasses scattered throughout the section and is locally recrystallized to metaquartz. Well-developed quartz overgrowths represent a restricted occurrence in the member and are found in association with mature, arkosic detritus (Figure 7d).

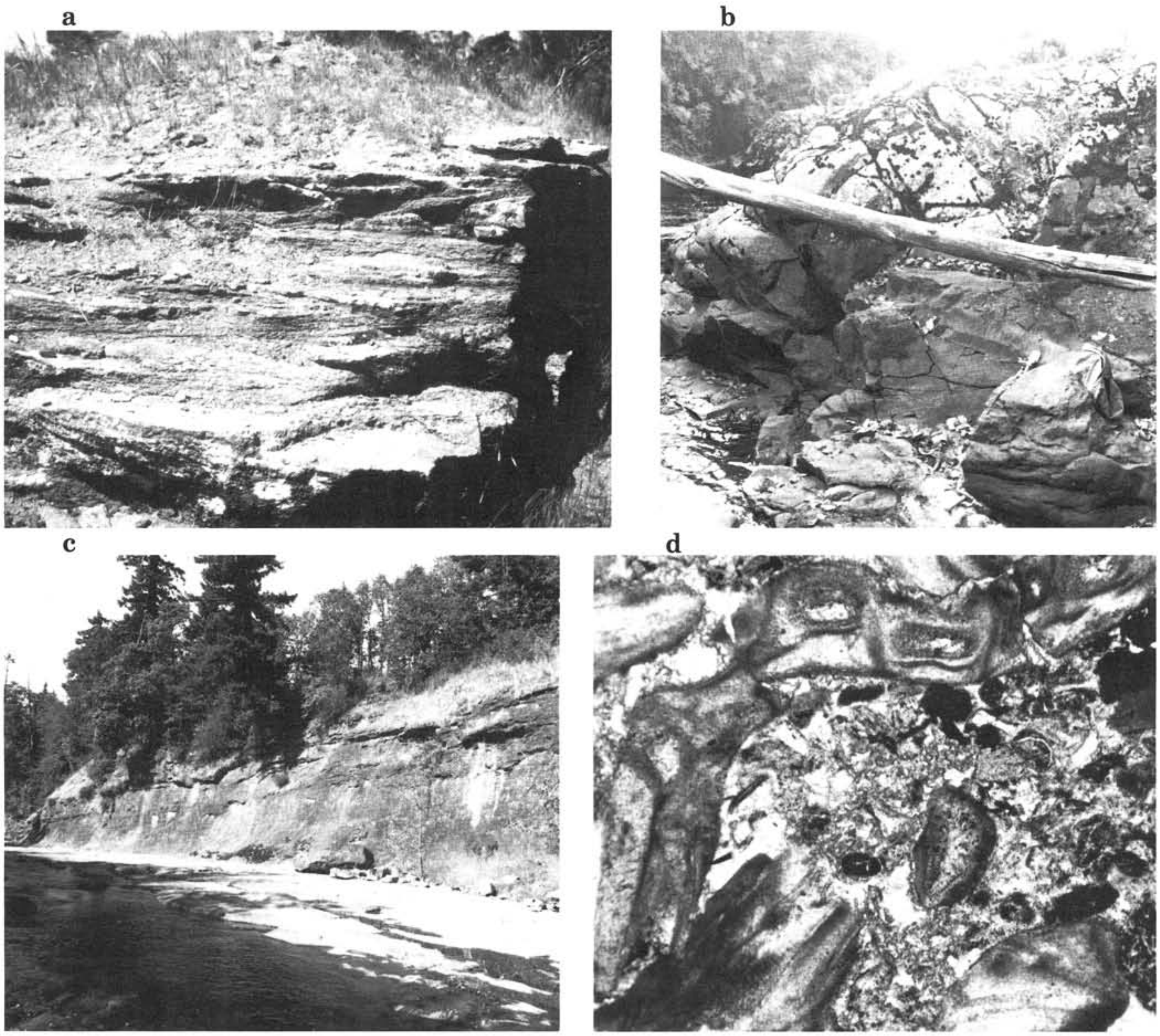

Figure 6. a. Megaripple cross-stratification from cross-stratified limestone facies. Outcrop is exposed approximately 5 km northeast of Marquam, Oregon. b. Exhumed shoal exposed in valley of Butte Creek. Base of feature is surrounded by barnacle debris enclosing petrified log. c. Amalgamated sandstone facies exposed approximately 200 m downstream from the Scotts Mills bridge over Butte Creek. d. Fossiliferous Marquam Member volcanic arenite. Bioclastic components are barnacle plate fragments. Field is 2.5 centimeters (cm) across.

Facies interpretation: The distribution of Abiqua Member facies is an indirect effect of the Little Butte basalt paleotopography. Widespread scouring with the development of scour-and-swell lags was common in close proximity to the ancient basaltic headland in the northern part of the study area. Great volumes of sediment were entrained in southerly longshore transport, resulting in the thorough admixture of northerly derived extrabasinal sands with pyroclastic debris from the ash-mantled landscape to the east. The development of cumulative calcrete horizons permits calculations on the timing of Abiqua Member sedimentation. Reineck and Singh (1980), in summarizing the studies of Gile and others (1966), Reeves (1970), Gardner (1972), and Gouldie (1973), suggest that "calcrete is formed near surface in stable geomorphic areas, where ... there is negligible sediment deposition." Leeder (1975) describes massive calcretes formed under a semiarid flood basin setting as requiring a minimum of 10,000 years.

Depositional environments associated with Abiqua calcretes are comparable with modern calcrete-forming environments. Assuming Leeder's minimum time constraint, periods of geomorphic stability on the order of 10,000 years were punctuated by brief periods of instability and aggradation of Abiqua sediments. The 1-m average spacing of Abiqua calcretes yields an average sedimentation rate of 1 m per 10,000 years to the 250-m-thick section. At this rate, a minimum of 2.5 million years would be required for Abiqua deposition.

Crooked Finger Member

The Crooked Finger Member includes more than 200 m of weakly consolidated, immature volcaniclastic detritus with interbedded coals. The best exposures flank Crooked Finger Ridge (which is the divide between Abiqua and Butte Creeks) and crop out along the valleys of Butte, Abiqua, and Coal Creeks. Physiographically, the unit forms irregular, lobate slopes with land-

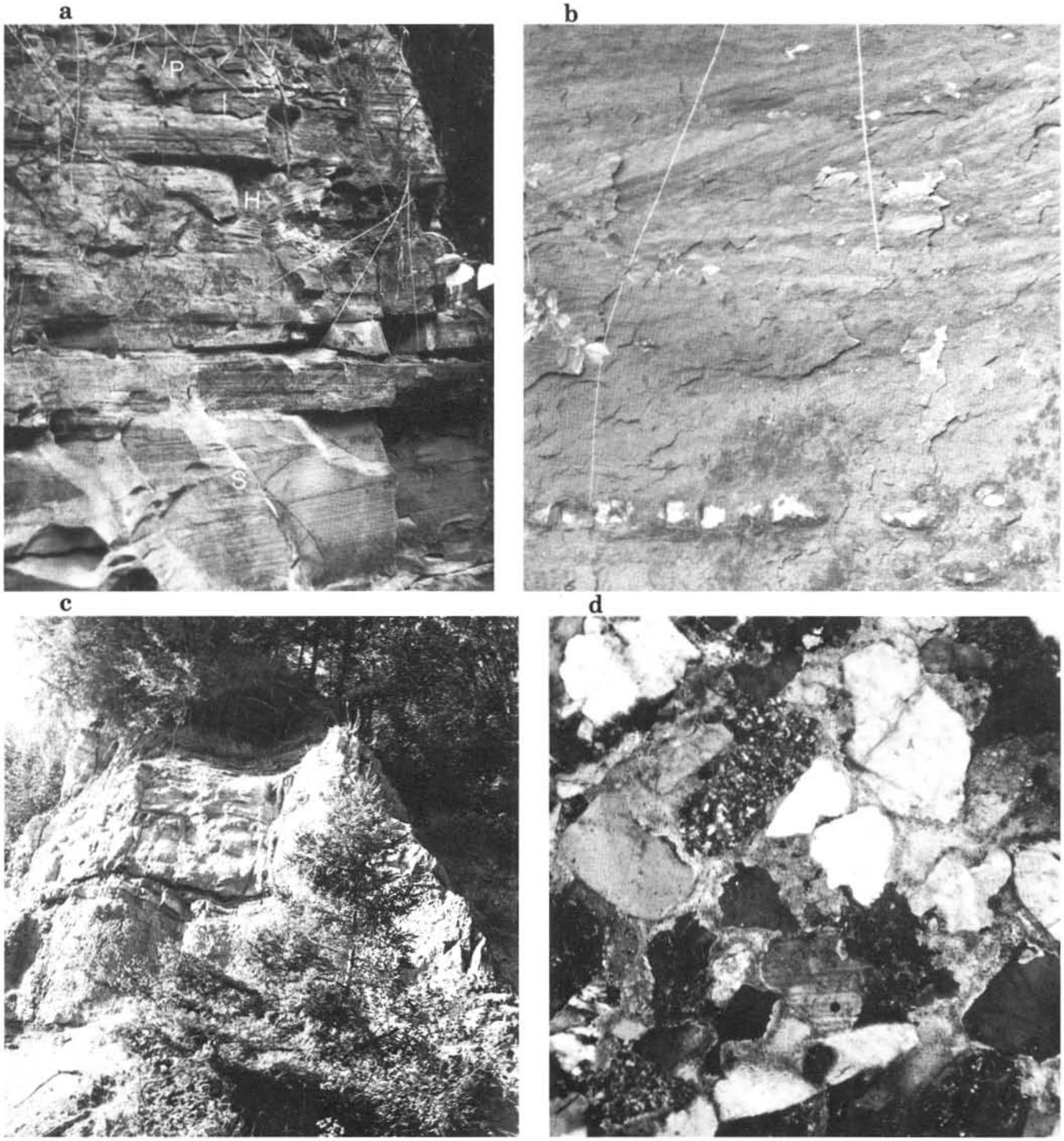

Figure 7. a. Littoral sand sequence from the Abiqua Member, exposed along Abiqua Creek. P = parallel lamination; H= high-angle cross-stratification; S = low-angle swash-cross-stratification. b. Calcrete horizon (base of figure) associated with epsilon cross-stratification. c. Storm-deposited coquinoid sandstone sequence exposed along Butte Creek Road. d. Photomicrograph of Abiqua Member volcanic arkose. Field is 0.25 cm across.

sliding in the south-central and southwestern portions of the study area. Owing to its weakly consolidated nature, the unit is poorly exposed and supports a thick soil and vegetation cover.

The unit stratotype is between the 880- and 1,010-ft elevation along Butte Creek. A reference section is designated east of the confluence of Butte and Coal Creeks in the southwest corner of sec. 32, T. 6 S., R. 2 E., along Coal Creek. A second reference section is situated in the southern half of sec. 13, T. 7 S., R. 1 E., along Abiqua Creek.

Lithology and distribution: Exposed Crooked Finger sediments are medium gray to brown, with reddish-brown oxidized patches on weathered surfaces. Fresh samples are bluish gray to drab green and resemble those of the Marquam Member. Coals of variable grade characterize the unit in combination with an abundance of muddy, tidally influenced channel-fill deposits.

Coal beds on the order of 40 centimeters (cm) thick are irregularly shaped, turbid masses of ferruginous clay supporting angular plagioclase feldspar grains. Accessory constituents of Crooked Finger Member sediments include biotite, pumice fragments, and locally concentrated glass shards. Additionally, spores and pollen are commonly preserved throughout the unit.

Facies interpretation: Deposits of the Crooked Finger Member closely resemble those of high-sinuousity streams as described by Moody-Stuart (1966) and Reineck and Singh (1980). The deposition of coal-bearing fluvial sequences of the Crooked Finger Member occurred in swampy alluvial lowlands landward of the Abiqua beach ridge system. These swampy areas represent the landward extension of the Little Butte embayment. Along this structurally controlled low, meandering and anastomosing fluvial systems flowed parallel to the axis of the embayment. Near the strand, the fluvial systems were diverted by the Abiqua beach ridge system. Modern depositional systems analogous to the Crooked Finger/Abiqua system are described by Coleman (1976) and by Ruxton (1970). These authors describe facies distribution along the wave-dominated San Francisco and Senegal Deltas and from young volcanic arc terrain in Papua, New Guinea.

PETROLOGIC RELATIONSHIPS: SCOTTS MILLS FORMATION SANDSTONES

Compositional plots of sandstones from the Marquam, Abiqua, and Crooked Finger Members are presented in Figure 9. Sandstones representative of each unit were selected for modal analysis. A point count of more than 100 grains provided the modal percentages plotted on the ternary diagrams. The results of grain counts of Scotts Mills Formation sandstones are summarized in Table 1.

QFL and QmPK diagrams are compared with similar data from Dickinson and Suzcek (1979) (Figure 9a). Those authors were able to discern discrete fields indicative of tectonic provenance. In both diagrams, the Marquam and Crooked Finger Members plot in the undissected magmatic arc field. Abiqua sandstones overlap the dissected arc field in the QFL plot (Figure 9a) and are transitional between the dissected and undissected arc fields on the QmPK diagram. This latter relationship suggests mixing of detritus originating in diverse source terrains.

An additional ternary diagram (QUpcTpc) plots twinned and untwinned plagioclase (Tpc and Upc, respectively) against quartz (Q) (Figure 9b). Again, sandstones of the Scotts Mills Formation plot in two distinct fields, with the Marquam and Crooked Finger Members showing an enrichment in twinned plagioclase. Plagioclase in Little Butte basalts is almost wholly twinned, and zoning is common. The predominance of twinned plagioclase in these units reflects their common Little Butte basalt provenance.

The QFL and QUpcTpc plots were compared by drawing tie lines connecting plots of individual sample compositions between the two diagrams (Figure 9b). Abiqua sandstone compositions show a pronounced covariance between quartz and untwinned plagioclase feldspar. The high proportion of quartz in these sediments implies a source rich in modal quartz. This silicic provenance contrasts sharply with that of the Marquam and Crooked Finger Members, which were derived from the erosion of mafic volcanic flows.

SCOTTS MILLS FORMATION AGE AND MARINE FAUNA

Marine environments from littoral rocky/sandy to middle and outer neritic are indicated by Marquam and Abiqua Member invertebrate faunas. The littoral sandy facies is best reflected in the Abiqua but does develop in some horizons of the Marquam (Table 2).

Within the lower two Scotts Mills members (Marquam and lowermost Abiqua), all of the faunas are assignable to the uppermost Oligocene Juanian West Coast provincial molluscan stage. Many of the well-preserved faunas are further assignable

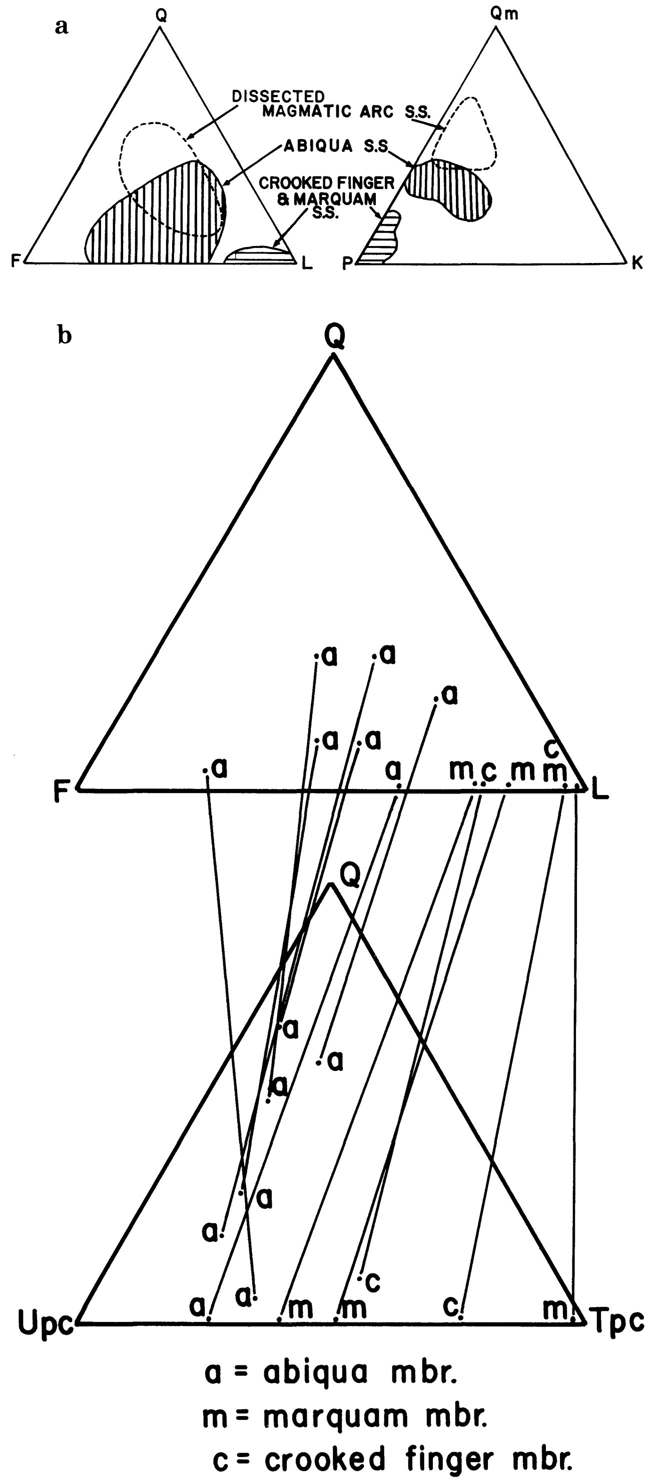

Figure 9. a. Ternary compositional plots of the Scotts Mills Formation sandstones. Q = quartz; F = feldspar; L = lithic fragments; QM = monocrystalline (single-grained) quartz; P = plagioclase; K = potassium feldspar. Dashed line = dissected magmatic arc-type sandstones (from Dickinson and Suzcek, 1979); horizontally lined field = Marquam and Crooked Finger Member sandstones; vertically lined field = Abiqua Member sandstones. b. Comparison of QFL and QUpcTpc plots. Upc = untwinned plagioclase; Tpc = twinned plagioclase; a = Abiqua Member; c = Crooked Finger Member; m = Marquam Member. Tie lines connect plots of individual samples.

Table 1. *Framework grain counts of selected Scotts Mills Formation sandstones*

SAMPLE	UNIT	QUARTZ				PLAGIOCLASE			K-SPAR	VRF	VITRIC	OTHER
		S	SC	C	TTL.	T	U	TTL.				
BC-615	Marquam					10	10	20		80		
AC-452						3		3		97		
13-11						6	4	10		66	24	
13-8							2	2		80		fl. 18
13-1		2			2	10	8	18		80		
SC-560						7	21	28		52		fl. 12 SRF 8 gu. 2
BS-3	Abiqua	10	4	6	20	6	8	14	6	60		
WR-1030		6			6	6	20	26		30	38	
BC-785		2	4	4	10	18	30	48	2	38		bi. 2
AC-560		4			4	18	46	64	6	18		ch. 2
SW-750		8	14	6	28	2	12	14	8	34		bi. 6 ct. 4 MRF 6
6-3		22	4	4	30	8	24	32	2	28		bi. 2 ct. 2 msc. 2 MRF 4
11-5	Coal Creek					6	10	16		80		px. 4
AC-740						12	4	16		84		
10-13		2			2	2	10	12		86		
10-1		2			2		4	4		94		

Abbreviations used in table 1: Quartz- S, single grained; SC, semi-composite; C, composite; TTL., total in group; Plagioclase- T, twinned; U, untwinned; VRF- volcanic rock fragments; MRF- metamorphic rock fragments; SRF- sedimentary rock fragments; bi.- biotite, ch.- chlorite; ct.- chert; msc.- muscovite; gu.- glauconite; fl.- fossils; px.- pyroxene

to the *Echinophoria apta* zone of the upper Juanian. This level at approximately 24 million years before the present (m.y. B.P.) is the marine Oligocene high-water mark for the Oregon Western Cascades.

In addition to molluscs, two other related lines of evidence exist for the late Oligocene age assignment. Barnacles from the Marquam Member have been examined by Victor A. Zullo (personal communication, 1984). He reports species of *Balanus* and suggests that their presence here may represent an interval immediately below the Oligocene/Miocene boundary. This occurrence represents the oldest known North American incidence of the genus *Balanus.*

Linder and others (1983) have reported several species of the echinoid genera *Salenia, Kewia, Lytechinus,* and *Arbacia* from the base of the Abiqua Member. According to Wyatt Durham (personal communication, 1984), several elements of this echinoid assemblage suggest an assignment to the uppermost Oligocene.

MOLALLA FORMATION

Although a thorough analysis of the Molalla Formation is beyond the scope of this study, some discussion is warranted in view of its interfingering relationship with the Scotts Mills Formation. Additionally, the unit is treated here to clarify field relationships and to enumerate criteria on which the unit was mapped by Miller and Orr (1984a,b) and Orr and Miller (1984; 1986a,b).

Tuffaceous paleosols and volcanic conglomerates and agglomerates assigned by Peck and others (1964) and later by Hampton (1972) to the upper part of Wells' (1956) Little Butte Volcanic Series are included in the Molalla Formation of this report. The name "Molalla Formation" was first used by Harper (1946). A type section was not designated, and the unit was not described in detail.

In view of the lack of a unit stratotype, a principal reference section is here established along Molalla Forest Camp Road in the eastern half of sec. 6, T. 6 S., R. 3 E. To illustrate the variability of the unit, a supplementary reference section is designated in the vicinity of High Hill, sec. 28, T. 6 S., R. 2 E. These two reference sections are established to characterize sediments of the upper and lower portions of the Molalla Formation, respectively.

Lithology and distribution

Stream-deposited volcanic and pyroclastic materials are especially common along the western fringe of the study area. At the principal reference section, the Molalla Formation consists of interlayered tan and buff sandstone and gravel conglomerate underlain by darker basalt cobble and boulder conglomerate (Figure 10a). Gravelly lateral accretion foresets here are as much as 2 m thick and are overlain by cut-and-fill gravel lenses. These deposits are similar in character to the gravelly point-bar sequences of the Nueces River, Texas, described by Gustavson (1978).

Gravelly point-bar deposits exposed along Molalla Forest Camp Road grade vertically and laterally into thick, horizontally bedded deposits of alternating sandstone and claystone (Figure 10b). Sandstones are wavy to lenticularly bedded and display internal cross-stratification. The muddy strata in these sequences are passively draped over the coarser grained beds. The tops of the fine-grained strata are usually eroded and scoured directly beneath the overlying sandy stratum.

Lower Molalla Formation strata at the High Hill reference section consist of fine-grained pyroclastic detritus in homogeneous, bleached-white sets of weakly indurated ripple-bedded sandstones. These trough-cross-bedded stream deposits grade vertically and laterally into weakly consolidated, white- and rust-colored fine-grained tuffs. Pedogenic alteration in these sequences is indicated by the repetitive superposition of weakly developed alteration horizons subparallel to overlying lamellae of woody plant remains and carbonized leaves. The repetitive sequences from these settings were developed as soil processes altered the fluviatile deposits during very early diagenesis. Often these deposits are associated with abundant silicified wood fragments, some reaching over a meter in diameter.

Charred, permineralized fossil wood is ubiquitous throughout the Molalla Formation and is characterized by the development of transverse furrows formed as the wood shrank during burning. The abundance of burned wood in the Molalla suggests frequent forest fires. The seasonally dry climate reflected by the Abiqua Member calcretes and the proximity to active centers of

Table 2. *Diagnostic and common molluscan taxa from the Marquam and basal Abiqua Members, Scotts Mills Formation*

Gastropoda

Acteon chehalisensis (Weaver)
Aforia cf. *canyonensis* Armentrout
Bruclarkia cf. *oregonensis* (Conrad)
Calyptraea diegoana (Conrad)
Crepidula praerupta Conrad
Echinophoria apta (Tegland)
Ficus modesta (Conrad)
Liracassis cf. *cordata* Armentrout
Musashia weaveri (Tegland)
Natica weaveri Tegland
Polinices washingtonensis (Weaver)

Pelecypoda

Acuka gettysburgensis (Reagan)
Callista pittsburgenis (Dall)
Chlamys sp.
Diplodontia parilis (Conrad)
Limopsis cf. *carmanahensis* Clark
Lucinoma hannibali (Clark)
Macoma arctata Conrad
Macoma vancouverensis (Clark and Arnold)
Modiolus restorationensis (Van Winkle)
Mytilus hannibali Clark and Arnold
Mytilus mathewsonii Weaver
Ostrea spp.
Pitar sp.
Pitar oregonensis (Conrad)
Portlandia chehalisensis (Arnold)
Solemya dalli Clark
Solen lincolnensis (Weaver)
Spisula albaria (Conrad)
Tellina townsendensis Clark

pyroclastic volcanism may have encouraged frequent conflagrations.

Facies interpretation

Stacked paleosols in the Molalla Formation are indicative of extended periods of limited sedimentation. Intervening periods of rapid sedimentation may have occurred in response to geomorphic instability accompanying the destruction of the vegetational cover by fire. Permineralized burned and charred wood throughout the Molalla and the widespread occurrence of thick ripple-bedded sandstone sequences support this. Cyclic periods of geomorphic stability/instability are indicated in both the Abiqua Member of the Scotts Mill Formation and the Molalla Formation. Longer term perodicity for major pyroclastic phases along the Western Cascades was originally suggested by McBirney and others (1974).

The sandstone and claystone sequences exposed along Molalla Forest Camp Road were developed as flow from the adjacent channels rose above the river bank and onto the flood plain during flood events. The sandy portions of the individual sequences were deposited during the peak of the flood, when current velocities were at a maximum. During waning of the floods, muds were deposited from suspension, draping over the sandy portions. Subsequent overbank floods repeated the process, and thick sequences of sheetflood deposits resulted.

The facies distribution within the Molalla Formation section delineates the channel of a major river system comparable in size to the modern Molalla River. Channel deposits in the eastern part of the study area are flanked by thick accumulations of sheetflood deposits. Toward the west, these deposits give way to well-drained paleosols and cross-stratified tuffaceous sediments that interfinger with coal-bearing strata of the Crooked Finger Member. Here, sediments of the Molalla Formation represent terrace deposits associated with the marginal areas of the Crooked Finger alluvial system.

Stratigraphic relationships indicate that sedimentation in the Crooked Finger alluvial lowland had ended prior to the deposition of upper Molalla Formation strata. Rather than being indicative of two separate, genetically unrelated drainage systems, alluvial sediments of both the Crooked Finger Member and the Molalla Formation are considered to have been deposited by an ancestral Molalla River. Upper Molalla Formation sediments may have been deposited as drainage was deflected to the north during folding of the Scotts Mills anticline (see drawings on front cover).

Alternatively, reorganization of the pre-existing drainage may have followed the deposition of intracanyon Columbia River basalt flows. Tuff clasts in the Crooked Finger suggest the development of antecedent drainage during folding. The elongate interfluve separating the valleys of Butte and Abiqua Creeks may reflect the topographic inversion of intracanyon flows that blocked drainage across the Scotts Mills anticline. This feature parallels paleocurrents in the underlying strata and shows a distinctly channel-form shape. The diversion of drainage by intracanyon flows explains the absence of Molalla Formation contact relationships with Columbia River Basalt Group strata.

Deposition of the lower and middle Miocene Molalla Formation occurred along a humid-climate fluvial system originating in the Little Butte highlands to the east. Deposition was characterized by intermittent sedimentation rates and poorly developed, rapidly buried soils. The unit accumulated under a warm-climate, broad-leaf forest cover (Wolfe, 1969).

Age relationships

Miller (1984), Miller and Orr (1984a,b), and Orr and Miller (1984; 1986a,b) included the upper pyroclastic portion of the Little Butte Volcanic Series with the Molalla Formation during detailed mapping of the area. Hampton (1972) had followed the opposite approach in his map of the Salem-Molalla Slope area, including the Molalla Formation in the Little Butte Volcanic Series.

We consider the Molalla as a distinct formation for several reasons. Sediments assigned to the Molalla Formation in this report clearly overlie an erosional surface of considerable relief developed on basaltic flows of the Little Butte Volcanic Series. Marine sediments of the Scotts Mills Formation rest on this same unconformity, and portions of the latter interfinger with Molalla Formation strata. These relationships indicate that considerable time separates the extrusion of the Little Butte basalts and Molalla Formation volcanism.

The interfingering relationship of fossiliferous strata of the Scotts Mills Formation with portions of the Molalla Formation suggests an early Miocene age for the upper portions of the latter unit. These relationships are best displayed at the High Hill reference section. Floral remains scattered throughout the unit were considered to be equivalent in age to those in the lower Miocene Eagle Creek Formation by R.W. Brown (in Trimble, 1957). Additionally, the Molalla Formation has been dated on the basis of floral remains by Wolfe and Brown (in Peck and others, 1964) as early Miocene. More recently, Wolfe (1969)

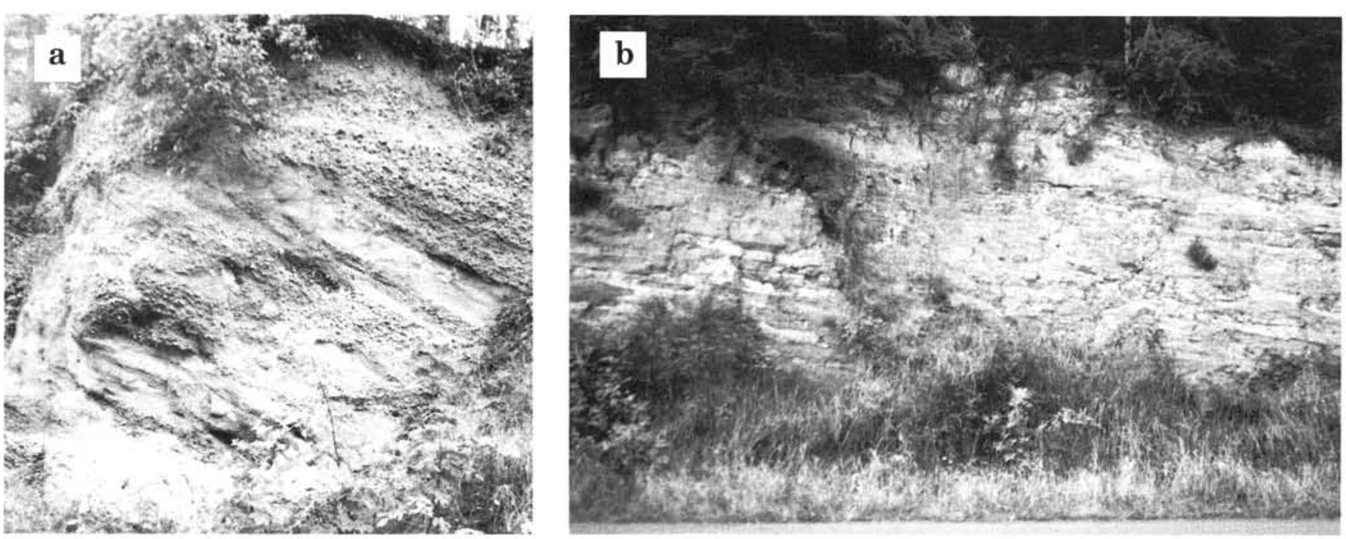

Figure 10. a. Lateral accretion foresets developed during migration of gravelly channel. Outcrop exposed along Molalla Forest Camp Road in association with Molalla type section. b. Overbank sequence comprised of repetitive sand-clay couplets, exposed along the Molalla Forest Camp Road.

recognized two floras from the Molalla area as post-Columbia River Basalt Group age. Obradovich (in Walker and others, 1974) dated the Molalla flora at 12.2 and 12.9 m.y. B.P., or middle Miocene.

The younger ages for the Molalla Formation were obtained from floras near the top of the nearly 300-m-thick Molalla Formation section exposed along Molalla Forest Camp Road, above the Molalla River. The older dates for the unit were obtained from lower portions of the section, in some cases close to the unconformity with the Little Butte basalt.

The present authors assign an early to middle Miocene age to the Molalla Formation. We extend the age to include the early Miocene in light of the interfingering nature and coincident stratigraphic position of the Molalla and Scotts Mills Formations and the early Miocene age of leaves from the Molalla Formation (e.g., U.S. Geological Survey paleobotanical loc. 8292).

PALEOGEOGRAPHY AND GEOLOGIC HISTORY

During Marquam deposition, the Little Butte basalt formed a headland in the north of the study area, with stacks and wave-cut platforms to the south and west (see artwork on front cover). According to Peck and others (1964), the Little Butte flows were extruded along a north-trending ancestral Cascade Arc and were significantly eroded by late Oligocene time. The irregular rocky coastline along which Marquam deposition occurred was characterized by deep marine embayments, steep submarine slopes, and oligomictic basaltic detritus. The end of Marquam Member deposition coincides with a major pyroclastic eruptive phase along the Cascade Arc near the Oligocene/Miocene boundary (e.g., McBirney and others, 1974).

The dominantly marine Abiqua Member and the wholly terrestrial Molalla Formation include tuffaceous sediments derived from the erosion of ash-fall tuffs mantling the volcanic landscape to the east. In the terrestrial realm, weakly consolidated pyroclastic deposits were stabilized by soil development and forest vegetation. During periods of geomorphic instability, these sediments were rapidly eroded and transported basinward.

At the coast, tuffaceous detritus was shed into the sea along a prograding wave-dominated delta, then reworked into a broad, accretional beach ridge complex developed along the strandline. Longshore drift facilitated the mixture of extrabasinal detritus derived from as far east as the northern Rockies with locally derived tuffaceous detritus along the length of the late Oligocene-early Miocene strandline.

Landward of the Abiqua beach ridge system, the Crooked Finger Member was deposited in a flood basin/high sinuousity stream depositional environment. This thickly vegetated, swampy alluvial lowland trended toward the present northwest as the landward extension of the Little Butte embayment.

In middle Miocene time, the Columbia River basalts had been erupted, and major folding and faulting along the deeply incised sedimentary inlier was complete. These low-viscosity basalts drowned much of the sedimentary landscape. The greatest thicknesses of middle Miocene basalts accumulated in stream valleys incised prior to eruption and following the marine regression. Subsequent erosion selectively removed the less resistant sedimentary rocks, producing inverted volcanic topography.

DISCUSSION

The paleotopography of the underlying Little Butte basalt surface exerted control on the mid-Tertiary depositional systems described in this report. The littoral zone in a volcanic-arc setting characteristically hosts a narrow, poorly developed coastal plain with an abundance of rocky exposures. Embayments between these rugged rock-bound segments represent areas of thick detrital sediment accumulation and host areas where marine and alluvial constructional processes predominate. Because of the disequilibrium conditions under which ash-fall or -flow materials are deposited, they are often rapidly reworked and redeposited in these low-lying areas.

The great volumes of pyroclastic detritus shed into the Little Butte embayment ended Marquam Member sedimentation. Sedimentary mechanisms operating under the low sediment yield conditions of Marquam deposition became ineffective, and a rapid progradation of the strand ensued. In the terrestrial realm, alluvial deposits built out onto the low-lying areas that were associated with the more subdued basalt topography. In the marine environment, these materials were reworked along the Abiqua beach ridge complex during successive accretionary episodes.

Fluvial systems landward of the beach ridge system transported materials in a direction parallel to the axis of the embayment. Low-lying areas of the alluvial plain hosted widespread swamp deposition, and the better drained areas were the sites of flood plains or alluvial terraces. Aggradation of the drainage systems accompanied progradation of the strand, with thick sequences of fluvial sediments and stacked paleosols.

According to Van Atta (1971), arkosic sediments of the Scappoose Formation were deposited along the seaward margins of an ancestral Columbia River delta. Sediments of the Scappoose are compositionally similar to those of the Abiqua Member and were deposited less than 100 km north of the Little Butte embayment. The similarities and chronostratigraphic relationships between the two units suggest that a veneer of sandy arkosic detritus, in part derived from the continental interior, was deposited along the length of this middle Tertiary coastline.

Depositional environments described here are comparable to the modern deposits of Papua, New Guinea (Ruxton, 1970). The modern example shows an almost identical suite of depositional environments similarly distributed relative to the bedrock surface topography. Additionally, the two settings are lithologically analogous. The Papuan deposits are dominantly plagioclase and lithic fragments in size intervals less than fine sand. Coarse detritus is composed almost wholly of volcanic rock fragments. Sediments from both settings are dominantly immature, with the exception of mature beach ridge sediments.

CONCLUSIONS

The mid-Tertiary marginal marine sequence exposed along the Scotts Mills inlier records a remarkably diverse assemblage of well-preserved paleoenvironments. Several ancient depositional systems can be recognized, including a storm-deposited rocky coastline, an accretionary beach ridge complex, an alluvial lowland and swamp, and a humid-climate fluvial system. The Scotts Mills and Molalla Formation paleoenvironments are analogous to modern depositional systems in Papua, New Guinea, as well as to sedimentary deposits elsewhere along the Cascade Arc.

Sediments of the Scotts Mills and Molalla Formations record the response of both terrestrial and nearshore depositional systems to widespread pyroclastic volcanism along the early Cascade Volcanic Arc. Prior to the major pyroclastic phase marking the Oligocene-Miocene boundary along the Western Cascades, oligomictic intrabasinal sediments were deposited in the Little Butte embayment. The well-developed Little Butte basalt erosional surface and the paucity of sediments introduced into the nearshore environment indicate little magmatic or tectonic activity during the latter half of the Oligocene.

In contradistinction to the tectonic quiescence suggested for the middle to late Oligocene, sediments deposited during the early to early middle Miocene record a period of intense magmatic and tectonic activity. The beginning of this interval is marked by widespread pyroclastic volcanism along the length of the Cascade Arc. Following the ensuing progradation of tuffaceous strandline sediments, deformation occurred along a number of parallel northwest-trending folds. Subsequently, the incursion of middle Miocene intracanyon flows of the Columbia River Basalt Group led to a dramatic reorganization of pre-existing Western Cascade drainage systems.

On the basis of paleomagnetic evidence, Magill and Cox (1981) suggested that the clockwise rotation of microplates in the Pacific Northwest occurred in two discrete phases. Those authors concluded that the Oligocene represents a tectonically quiet interval separating Coast Range accretion and Basin and Range extension. This report provides an independent line of evidence supporting this conclusion.

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