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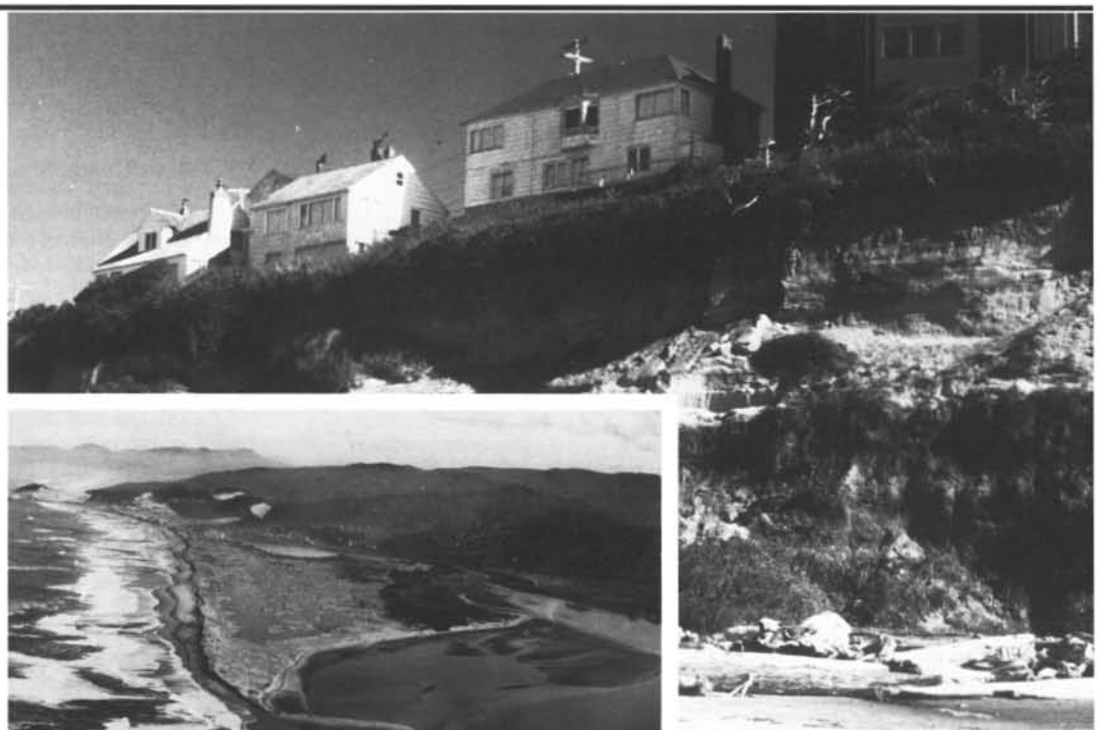

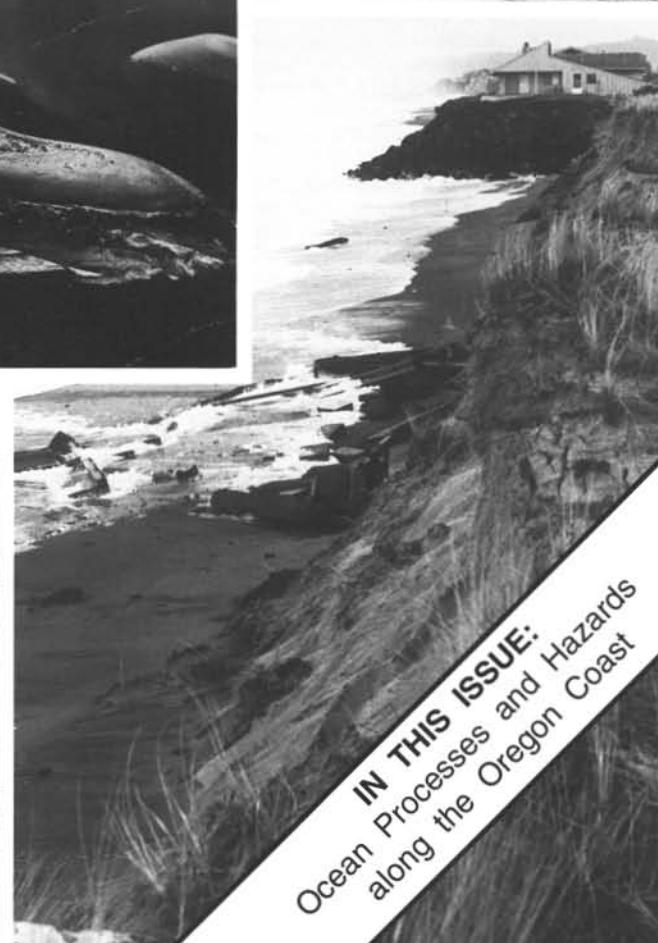

IN THIS ISSUE: Ocean Processes and Hazards along the Oregon Coast

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Information for contributors

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

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

Cover illustration

Photos from article beginning on page 3 and discussing ocean processes and hazards. Center photo: Breaching of Nestucca Spit during February 1978 storm. Oregon State Highway Department photo. Outside photos: Upper left: Progressive erosional destruction of Natatorium on Bayocean Spit. Photos courtesy of Tillamook Pioneer Museum. Upper right: Sea-cliff erosion in Lincoln City. Lower right: Erosion on Siletz Spit during December 1972. Lower left: Sea cliff at Jump-Off Joe, Newport, consisting of seaward-dipping Tertiary mudstones and uplifted Pleistocene marine terrace sands.

OIL AND GAS NEWS

Drilling activity at Mist Gas Field

Nahama and Weagant Energy completed its 1991 drilling program at Mist Gas Field, drilling a total of five exploratory wells and one redrill. Two wells and the redrill were successful gas completions, while the other wells were plugged and abandoned. The successful wells include the Columbia County 44-8-64, CER 14-26-64, and Columbia County 34-31-65 Redrill. The plugged wells include the Columbia County 23-35-75, LF 22-31-65, and Columbia County 34-31-65 (original hole).

Northwest Natural Gas completed the drilling at the Natural Gas Storage Project at Mist Gas Field, drilling two additional injection-withdrawal service wells. The IW 13b-11 was drilled in the Bruer Pool, and the IW 23d-3 was drilled in the Flora Pool.

DY Oil well plugged and abandoned

During November, DY Oil plugged and abandoned the Neverstill 33-30 well at Mist Gas Field. This well was drilled in 1989 and was no longer capable of economic production. It had a cumulative production of 62,127 mcf. □

DOGAMI sales office to move

The Oregon Department of Geology and Mineral Industries (DOGAMI) is moving to its new offices and sales/information center at the new State Office Building in Portland during the last week of February. From February 10 through March 10, there will be no over-the-counter sales service available to the public. Mail and phone orders, however, will be filled during this period. Callers with phone orders will be asked to leave their names and phone numbers, and their calls will be returned each day.

Although our move will temporarily affect our ability to serve you in person, we ask you to be tolerant because we know you will be pleased with our improved capabilities for meeting your publication, map, and natural-resource information needs at the new site. Before February 28, we can be reached at our old address and phone number (see box on left side of this page). After February 28, contact us at the new sales/information center, Suite 177, 800 NE Oregon St. #5, Portland, OR 97232, phone (503) 731-4444. □

To our readers

Our best wishes to you for a healthy and successful New Year!

The announced second part of the article on "How Geologists Tell Time" (November 1991 issue) will appear in our next (March) issue. We ask for your patience—and apologize for an error in the first part: The reference to "Figure 5" in the last paragraph on page 127 should have read "Figure 4," of course.

—Editors

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Beverly F. Vogt, Publications Manager

Ocean processes and hazards along the Oregon coast

by Paul D. Komar, College of Oceanography, Oregon State University, Corvallis, Oregon

INTRODUCTION

Early explorers of the Oregon coast (Figure 1) were impressed by the tremendous variety of its scenery. Today, visitors can still appreciate those same qualities. The low rolling mountains of the Coast Range serve as a backdrop for most of the length of its ocean shore. In the south, the Klamath Mountains extend to the coast, and the edge of the land is characterized by high cliffs being slowly cut away by ocean waves. The most resistant rocks persist as sea stacks scattered in the offshore. Sand and gravel are able to accumulate only in sheltered areas where they form small pocket beaches within the otherwise rocky landscape.

The more extensive stretches of beach are found in the lower lying parts of the coast. The longest continuous beach extends from Coos Bay northward to Heceta Head near Florence, a total shoreline length of some 60 mi. This beach is backed by the impressive Oregon Dunes, the largest complex of coastal dunes in the United States. Along the northern half of the coast there is an interplay between sandy beaches and rocky shores. Massive headlands jut out into deep water, their black volcanic rocks resisting the onslaught of even the largest storm waves. Between these headlands are stretches of sandy shoreline whose lengths are governed by the spacings between the headlands. Portions of these beaches form the ocean shores of sand spits such as Siletz, Netarts, Nehalem, and Bayocean. Landward from the spits are bays or estuaries of rivers that drain the Coast Range.

The first western explorers and settlers were attracted to the Oregon coast by the potential richness of its natural resources. Earliest were the traders who obtained pelts of ocean otter and beaver from the Indians. Later came prospectors who sought gold in the beach sands and coastal mountains but in many cases were content to settle down and "mine" the fertile farm lands found along the river margins. Others turned to fishing, supporting themselves by harvesting the abundant Dungeness crab, salmon, and other fish in the coastal waters. Also important to the early economy of the coast were the vast tracts of cedar and sitka spruce, a significance that continues to the present.

In contrast, today the most important "commodity" for the Northwest coast economy is the vacation visitor. Vacationers arrive in thousands during the summer months, but in spite of their numbers it is still possible to leave coastal Highway 101 and find the seclusion of a lonely beach or the stillness of a trail through the forest.

However, there is cause for concern that the qualities of the Oregon coast we cherish are being lost. Like most coastal areas,

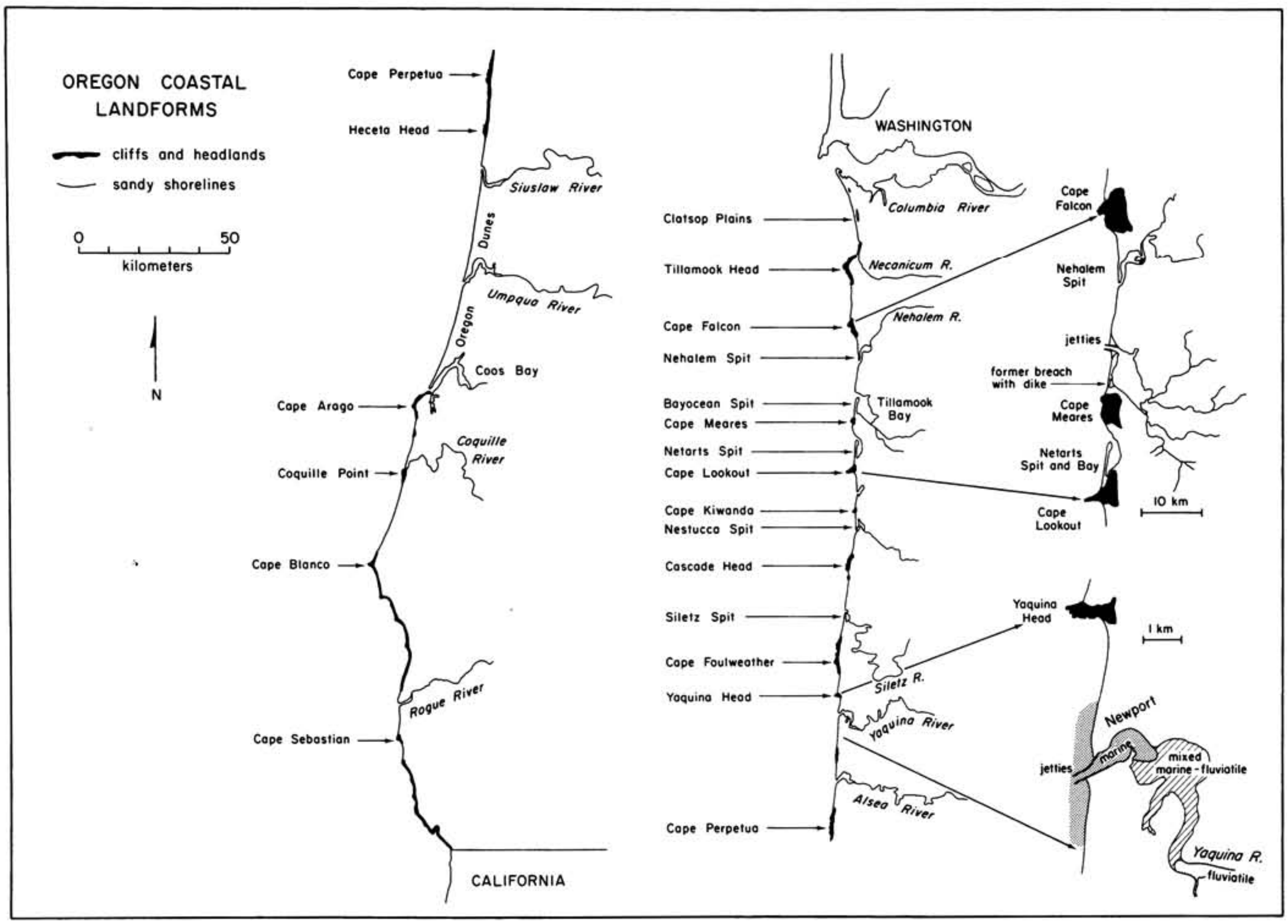

Figure 1. Coastal landforms of Oregon, consisting of stretches of rocky shorelines and headlands, separating pockets of sandy beaches. From Komar (1985).

Oregon is experiencing developmental pressures. Homes and condominiums are being constructed immediately behind the beaches, within the dunes, and atop cliffs overlooking the ocean. Everyone wants a view of the waves, passing whales, and an evening sunset, as well as easy access to a beach. These desires are not always compatible with nature, and as a result there are increasing problems with homes that are being threatened and sometimes lost to beach erosion and cliff landsliding.

Such problems can usually be avoided if one recognizes that the coastal zone is fundamentally different from inland areas because of its instability. This requires some knowledge of ocean waves and currents and how they shape beaches and attack coastal properties, and it requires an understanding and recognition of the land's potential instabilities that might cause disasters such as sudden landslides. A familiarity with the processes and types of problems experienced in the past can aid in the selection of a safe location for one's home. It can also enhance enjoyment of the coast and, it is hoped, lead to an appreciation of the qualities of the Oregon coast that must be preserved.

TECTONIC SETTING AND GEOMORPHOLOGY

The tectonic setting of the Oregon coast is extremely important to the occurrence and patterns of erosion. Especially significant is the presence of active sea-floor spreading beneath the ocean to the immediate west. New ocean crust is formed at the Juan de Fuca and Gorda Ridges, and the movement of the resulting plates is generally eastward toward the continent. These ocean plates collide with the North American plate (which includes the continental land mass). That collision zone lies along the margin of the coasts of Washington, Oregon, and northern California. There is also evidence that the oceanic plates have been undergoing subduction beneath the continental North American plate, evidence that includes the still-active volcanoes of the Cascades, the existence of marine sedimentary rocks accreted to the continent, and the occurrence of vertical land movements along the coast.

Most of the marine sediments deposited on the oceanic plates are scraped off during the subduction process and are accreted to the continental plate. The addition of ocean sediments to the continent has led to the long-term westward growth of the Pacific Northwest. The oldest rocks found in the Coast Range date back to the Paleocene and Eocene epochs, some 40-60 million years ago. These accreted marine sediments, mainly gray mudstones and siltstones, can be seen in many sea cliffs along the coast (see cover photo, lower left). As will be discussed in a later section, the presence of these mudstones is important to the erosion of sea cliffs and particularly the occurrence of landslides.

In addition to Tertiary mudstones, many sea cliffs contain an upper layer of clean sand (cover photo, lower left). These Pleistocene marine terrace deposits consist of uplifted beach and dune sands. In some areas, the Pleistocene sands form the entire sea cliff, with no outcrop of Tertiary mudstones beneath. The flat marine terrace seen in the photo is the lowermost and youngest of a series of terraces that in some places form a stairway up the flank of the Coast Range. Their presence documents that the Oregon coast has been tectonically rising for hundreds of thousands of years, while at the same time the level of the sea has oscillated due to the growth and retreat of glaciers.

The general uplift of the Northwest coast is also demonstrated by records from tide gauges where the hourly measurements are averaged for the entire year, removing the tidal fluctuations and leaving the mean sea level for that year (Hicks and others, 1983). Examples obtained by yearly averaging and covering up to 80 years are shown in Figure 2.

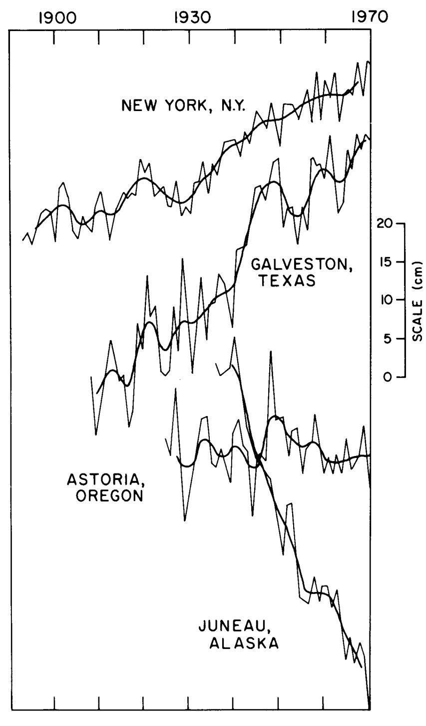

Figure 2. Yearly changes in sea levels determined from tide gauges at various coastal stations. After Hicks (1972).

Each record reveals considerable fluctuations in the level of the sea from year to year, with many small ups and downs. The sea level in any given year is affected by many oceanic and atmospheric processes that produce these irregular fluctuations. In spite of such irregularities, most tide-gauge records reveal a long-term rise in the sea that can in part be attributed to the melting of glaciers. The record from New York City is typical of such observations: in that example, the long-term average rise is 3.0 mm/year, about 12 in. per century (1 in. = 25 mm). The record from Galveston, Texas, also shows a rise, but the average rate is much higher at 6.0 mm/year (24 in. per century). The actual level of the sea cannot be going up faster at Galveston than at New York City—the discrepancy results from changing levels of the land that affect the record obtained at a specific tide-gauge site. It is known that the Galveston area is subsiding, so the 6.0-mm/year record from that tide gauge represents the combined effects of the local land subsidence plus the actual rise in sea level. An extreme case of this is Juneau, Alaska, which is tectonically rising at a rate that is faster than the rise in sea level. The Juneau tide-gauge record, therefore, indicates a net fall in the water level relative to the land. According to the record from the tide gauge at Astoria, Oregon, as included in Figure 2, the level of the sea there has remained relatively constant with respect to the land. This must indicate that during at least the last half century Astoria has been rising at just about the same rate as the sea. A detailed analysis of the measurements from the Astoria tide gauge indicates that the land is actually rising slightly faster than the water, the net increase in the land elevation relative to the sea being 0.1 to 0.2 mm/year. This change is small, amounting to 10 to 20 mm (<1 in.) of land elevation increase if continued for 100 years. Greater rates of uplift of the land must be occurring at Neah Bay on the north coast of Washington, the net rate there being 1.3 mm/year (5 in. per century) in excess of the global sea-level rise, and at Crescent City in northern California with 0.7 mm/year or 2.8 in. per century of net land emergence (Hicks and others, 1983).

Data from geodetic surveys collected by the National Geodetic Survey permit us to infer the movement of the land relative to the sea along the remainder of the Oregon coast. Vincent (1989) and Mitchell and others (1991) have analyzed the geodetic data along a north-south line extending the full length of the Oregon coast. Surveys made in 1931 and 1988 were compared to establish elevation changes; the values are graphed in Figure 3. The movement so determined is relative rather than absolute, so the elevation changes have been normalized to the bench mark in Crescent City. Accordingly, the elevation-change scale on the left of the diagram gives 0 for Crescent City. Positive values for other locations represent an increase in elevation relative to Crescent City, and negative values indicate reduced elevation relative to Crescent City (but could still involve tectonic uplift).

The overall pattern seen in Figure 3 indicates that the smallest uplift has occurred along the north-central coast between Newport and Tillamook, with progressively higher uplift further south and along the very north-

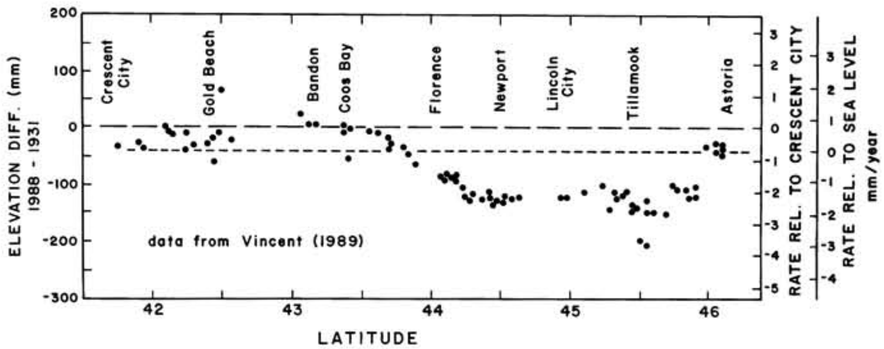

Figure 3. Elevation changes and the relationship to sea-level rise along the length of the Oregon coast from Crescent City in California north to Astoria on the Columbia River, based on repeated geodetic surveys along the coast. After Vincent (1989).

ernmost portion of the coast toward Astoria and the Columbia River. The first scale on the right of Figure 3 indicates the equivalent rates, the elevation changes divided by the lapsed time between surveys, 1988-1931 = 57 years. The differential rates are significant, for example amounting to 2-3 mm/year when comparing Astoria and the south coast with the Newport and Lincoln City areas.

It is possible to use the tide-gauge data to convert the elevation changes relative to Crescent City as they were determined by Vincent (1989) into rates compared with the global change in sea level. This is done simply by shifting the first scale on the right of Figure 3, the one that is relative to the Crescent City bench mark, by an amount of 0.7 mm/year as determined from the tide gauge at that location. This shift yields the rate scale furthest to the right in Figure 3, the rate of land-level change relative to the changing global sea level. A positive value again indicates that the elevation of the land is increasing relative to the sea, while a negative value corresponds to inundation of the land by the rising sea. This coast-wide shift of the scale by 0.7 mm/year (based on the tide gauge at Crescent City) indicates that Astoria at the far north is rising faster than the sea by an amount on the order of 0.1-0.2 mm/year, just as found by the tide gauge at that location—confirming the validity of Vincent's analysis of geodetic data to determine elevation changes and of the analyses undertaken to convert those data into a rate of change compared with the increasing level of the sea.

According to the results graphed in Figure 3, the southern half of the Oregon coast and the far north coast near Astoria are presently rising faster than the global sea level, while the central stretch between Newport and Tillamook is being submerged by the rising sea. The submergence rates are on the order of 1-2 mm/year (4-8 in. per century) and therefore are small, compared with submergence rates experienced on most coastlines: Rates of 4-6 mm/year (16-24 in. per century) are common along the east and Gulf coasts of the United States (Figure 2). The global rise in sea level has been estimated by various workers to be on the order of 1-3 mm/year (4-12 in. per century). The large range is due to the difficulty of separating that worldwide component from local tectonic and isostatic effects included in records from tide gauges. Assuming that the eustatic rise in sea level is on the order of 2 mm/year (8 in. per century), the results from Figure 3 indicate that the south coast of Oregon is tectonically rising at a rate of about 2-3 mm/year (8-12 in. per century), while the stretch between Newport and Tillamook is approximately stable, neither rising nor falling tectonically.

It is apparent that the along-coast differences in tectonic uplift versus changing levels of the sea deduced from Figure 3 will be relevant to spatial patterns of coastal erosion. However, there also appears to be a temporal change in the tectonics that would be important to erosion. Earthquake activity is generally associated with subduction zones such as the one in the Northwest—seismic events formed by the plates' scraping together as the oceanic plate slides beneath the continental plate. The Northwest coast is anomalous in that respect in that there have been no historic earthquakes that can be attributed to plate subduction.

However, recent evidence suggests that the plates are temporarily locked together and that the 200-year historical record from the Northwest is too limited to establish whether earthquakes do accompany subduction. This evidence has come from investigations of estuarine marsh sediments buried by sand layers, deposits suggesting that during prehistoric times portions of the coast have abruptly subsided, generating an extreme tsunami that swept over the area to deposit the sand (Atwater, 1987; Darienzo and Peterson, 1990; Atwater and Yamaguchi, 1991).

Based on the number of such layers found in Willapa Bay, Washington, and Netarts Bay, Oregon, it has been estimated that catastrophic earthquakes have occurred at least six times in the past 4,000 years, at intervals ranging from 300 to 1,000 years. The last recorded event took place about 300 years ago. Therefore, there is strong evidence that major subduction earthquakes do indeed occur along the Northwest coast—but with long periods of inactivity between events. An earthquake releases strain built up by subduction, and the result is that some areas of the coast drop by 1-2 m (3-6 ft) during the release, whereas other areas undergo minimal subsidence. Between earthquake events the strain is accumulating, and this produces a general uplift of the coast as recorded by the tide gauges and geodetic surveys within historic times (Figures 2 and 3).

Another potential change in the present-day pattern of sea-level rise versus coastal uplift is associated with predictions for an accelerated rise in sea level associated with future greenhouse warming. Global temperatures have been predicted to increase from 1.5° to 4.5° by the year 2050 (National Research Council, 1983). Those predictions in turn have led to a variety of estimates for accelerated sea-level rise, caused by increased glacial melting and thermal expansion of seawater. For example, a report by the National Research Council (1987) predicts that by the year 2025 the global sea level will rise by 10-21 cm (4-8 in.). Although this may seem insignificant, the effects on sandy shorelines may be magnified 100 times in the horizontal direction, resulting in shoreline erosion of 10-21 m (33-70 ft).

There are many uncertainties in the analyses of sea-level rise resulting from greenhouse warming, and therefore the resulting predictions have been controversial among scientists. Different investigators who studied sea-level curves derived from tide gauges have reached conflicting results, some concluding that they see an increase in the rate of rise in recent decades, others concluding that they do not. Despite the uncertainties, there is a growing consensus that some increased rate of sea-level rise can be expected in the next century. This recognition has led to recommendations that future sea levels be given more serious consideration in coastal management decisions.

OCEAN PROCESSES AS AGENTS OF EROSION

The Northwest coast is one of the world's most dynamic environments. Ocean waves and currents continuously reshape the shoreline. Portions of the beach are cut away, while others are built out. Severe storms strike the coast during the winter, generating strong winds that drive rain against sea cliffs and homes and form huge ocean waves that crash against the shore. Beaches give way to waves and currents, retreating back toward the land. At times, this beach loss continues until the erosion threatens homes and motels and cuts away at public parklands.

Ocean waves

The extreme seasonality of the Oregon climate results in parallel variations in ocean processes and exerts the primary control on natural cycles observed on beaches. The varying energy of ocean waves parallels the seasonally varying storm winds, because the strength of those winds is the primary factor in causing the growth of waves. In general, the greater the wind velocities blowing over the ocean's surface, the higher the resulting waves. Other factors are involved in addition to the wind speed. One is the duration of the storm—the longer the winds blow, the more energy they are able to transfer to the waves. The third factor is the fetch, the area or ocean expanse over which the storm winds are effective. Fetch operates much like storm duration in that the area of the storm governs the length of time the winds are able to act directly on the waves. As the waves are forming, they move across the ocean's surface and may eventually pass beyond the area of the storm so they no longer acquire energy from the winds. The importance of fetch is apparent when one contrasts wave generation on the ocean with that on an inland lake. The fetch on the lake can be no greater than its length, so the waves can acquire only a small amount of energy from winds before they cross the entire lake and break on the shore.

Wind-generated waves are important as energy-transfer agents. They first obtain their energy from the winds, transfer it across the expanse of the ocean, and finally deliver it to the coastal zone when they break on the shoreline. Therefore, a storm need not be in the immediate coastal zone. Waves reach the shores of Oregon from storms all over the Pacific Ocean, even from storms in the southern hemisphere near Antarctica. Our largest waves are derived, however, from winter storm systems moving down from the north Pacific and Gulf of Alaska.

Ocean waves reaching the shores of Oregon are measured daily by a unique system, a microseismometer like those that are usually employed in measuring small earth tremors. In this application, the microseismometer senses ground movements produced by ocean waves as they reach the shore and break. Many Coast Guard stations in the Northwest now use this system to obtain better estimates of wave conditions than they formerly obtained by visual determination. A microseismometer system is also in operation at the Oregon State University Hatfield Marine Science Center in Newport, one that is connected to a recorder to obtain a permanent record of the waves. This system has been in operation since November 1971 and has yielded the longest continuous record of wave conditions on the west coast of the United States. These measurements have been valuable in research examining the causes of beach erosion along the Oregon coast.

It might come as a surprise that a microseismometer in the Marine Science Center can provide records of ocean waves—after all, the Center is nearly 2 mi from the ocean. However, even more impressive is the fact that the waves can be detected on the seismometer at Oregon State University in Corvallis, 60 mi inland. When the surf is high on the coast, its effects can be seen as small jiggles in the seismometer recordings.

The microseismometer in the Marine Science Center differs from normal seismometers in that it is so tuned as to amplify small tremors, whether they are caused by earthquakes too minor to be felt or generated by ocean waves along the coast. In order to use the recordings from the microseismometer to measure ocean waves, it was necessary to first calibrate the system (Zopf and others, 1976; Creech, 1981). This calibration was accomplished by obtaining direct measurements of waves in the ocean at the same time their tremors were measured with the microseismometer. The direct measurements of waves were taken with a pressure transducer, an instrument that rests on the ocean bottom and records wave pressures that are directly proportional to the heights of the waves passing over the transducer.

The pressure transducer, the most commonly used instrument for measuring ocean waves directly, would be preferable to the microseismometer. However, winter storms experienced along the Northwest coast are so intense that they usually destroy pressure transducers or other wave-measuring instruments that must be placed in the water. On this coast, we need a microseismometer that can remain in the Marine Science Center, safe from the reach of waves.

Although the direct comparisons between the pressure-transducer records and those obtained with the microseismometer were continued for only a few months, the results showed that the motions on the microseismometer are directly proportional to the heights of the offshore waves. Now only the microseismometer is needed to monitor daily ocean-wave conditions.

An example of the daily wave measurements obtained from the microseismometer is shown in Figure 4, covering the period from mid-December 1972 through January 1973. Most apparent in this series are the storm waves that struck the Oregon coast during Christmas. The breaker heights at that time reached 7 m, about 23 ft, roughly the height of a three-story building. This reported height represents what is termed a "significant wave height", defined as the average of the highest one-third of the waves.

Thus, the significant wave height can be evaluated from measurements obtained with wave-sensing instruments. However, it turns out that the significant wave height also roughly corresponds to a visual estimate of a representative wave height. This

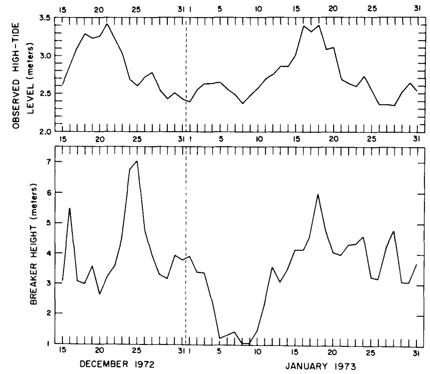

Figure 4. An example of daily variations in wave conditions measured by the microseismometer at Newport, covering the interval from December 1972 through January 1973. From McKinney (1977).

is because an observer normally tends to weight the observations toward the larger waves, ignoring the smallest. There will, of course, be many individual waves that are still higher than this reported significant wave height, which remains something of an average. Measurements have shown that the largest wave height during any 20-minute time interval will be a factor of about 1.8 times the significant wave height (Komar, 1976). Therefore, when the graph of Figure 4 indicates the occurrence of a significant wave height of 7 m during Christmas 1972, there must have been individual waves having heights of about 1.8 x 7 m = 12.6 m (>41 ft)! As might be expected, there was considerable erosion along the coast during that storm, the severest impact occurring at Siletz Spit on the mid-Oregon coast.

Figure 5 gives an example of the annual changes in wave-breaker heights as measured by the microseismometer. The measurements were obtained from July 1972 through June 1973, but they are typical of annual variations (Komar, Quinn, and others, 1976). These data again represent significant wave heights. The solid line gives the average of significant breaker heights that were measured during each one-third-month interval. It shows that the breakers are on the order of 2 m (7 ft) high during the summer months, nearly doubling to about 4 m (13 ft) in the winter. The dashed lines show the maximum and minimum breaker heights that occurred during those one-third-month intervals and provide a better impression of the effects of individual winter storms. The largest waves recorded within this 1972-73 period reached the coast during the final third of December 1972, as shown on a daily basis in Figure 4.

Although extremely high, the waves during that December 1972 storm are well below the largest that have been measured off the Northwest coast. In the early 1960s, a wave-monitoring program on offshore

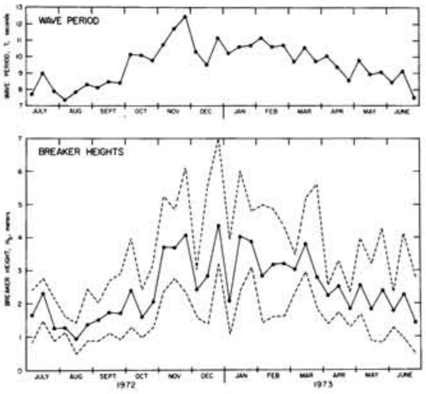

Figure 5. The monthly variations of wave breaker heights and periods at Newport, illustrating the occurrence of higher wave conditions during the winter months. Solid line is for mean heights (significant wave heights) for one-third-month intervals; dashed lines are for largest and smallest breakers for those intervals. From Komar, Quinn, and others (1976).

rigs exploring for oil measured an individual wave at a height of 29 m (95 ft) (Rogers, 1966; Watts and Faulkner, 1968). This is close to the 112-ft height of the largest wave ever reliably measured in the ocean, observed from a naval tanker traveling from Manila to San Diego in 1933 (Komar, 1976). All of the measurements on the Oregon coast confirm that it has one of the highest wave-energy climates in the world.

Beach cycles on the Oregon coast

Beaches respond directly to the seasonal changes in wave conditions. The resulting cycle is similar on most coastlines and is illustrated schematically in Figure 6. The beach is cut back during the winter months of high waves, when sand is eroded from the shallow underwater and from the beach berm (the nearly horizontal part of the beach profile that is above the high-tide line). This eroded sand moves to deeper water, where it then accumulates in offshore bars, approximately in the zone where the waves first break as they reach the coast. Sand movements reverse during the summer months of low waves, moving back onshore from the bars to accumulate in the berm. Although this cycle between two beach-profile types is approximately seasonal due to changing ocean waves, the response is really one to high storm waves versus low regular swell waves. At times, low waves can prevail during the winter, and the beach berm may actually build out, although not generally to the extent of the summer berm. Similarly, should a storm occur during the summer, the beach erodes.

This cycle has been demonstrated to occur on Oregon beaches, just as it has been observed along other coasts. In one study, profiles were obtained monthly during the winter of 1976-77 from two beaches, that to the south of Devil's Punchbowl at Otter Rock and the one at Gleneden Beach south of Lincoln City (Aguilar-Tunon and Komar, 1978). These two beaches were selected because of their contrasting sand sizes that produce marked differences in overall slopes of the profiles. The sediment grain size is the primary factor that governs the slope of a beach: the slope increases as grain size increases. Gravel beaches are the steepest, their slopes sometimes reaching 25°-30°, whereas the overall slope of a fine-sand beach may be only 1°-2°. This is seen in the comparison of the beach profiles at Gleneden Beach and Otter Rock (Figure 7), the beach at Gleneden being coarser and hence steeper.

The month-by-month changes in the profiles at Gleneden Beach are shown in Figure 8. These profiles were obtained with standard surveying gear and by wading into the water. They do not show the offshore bars, which were too deep to reach. However, these profiles do illustrate the rapid retreat of the beach as the winter season develops. Erosion began as early as October and continued through the spring. The return of sand to the berm and the buildup of the beach did not take place until April through June. The cycle of profiles at the Otter Rock beach was basically the same, at least in its timing. However, the magnitude of change was much smaller than at Gleneden Beach. Sand elevations at Gleneden changed by as much as 2-3 m (8 ft) (Figure 8), while the changes at Otter Rock amounted to less than 1 m (3 ft). This again can be attributed to differences in grain sizes between these two beaches. In general, the coarser the grain size of the beach sand, the larger the changes in its profile in response to varying wave conditions. The response to storms is also much faster for the coarser grained beach—the storm waves not only cut back the coarser beach to a greater degree but also erode it at a much faster rate. Here nature goes counter to what might intuitively have been expected.

The greater response of coarser grained beaches to storm waves is of importance to coastal-erosion processes, since the waves are able to rapidly cut through the beach to reach homes and other structures. This points to the general role of the beach as a buffer between the ocean waves and coastal properties. During the summer, when the beach berm is wide, the waves cannot reach the properties. So, erosion is not a problem, thanks to the buffer protection offered by the beach. However, when the beach is cut back during the fall and early winter, it progressively loses that buffering ability, and property erosion is more likely. If a storm strikes the coast in October, there may be enough beach to serve as a buffer so that property erosion does not occur. It is only when the beach berm completely disappears and the waves can wash against the cliffs and foredunes that the potential for property losses is great. This is often the condition from about November through March, but in fact the extent of the remnant berm is extremely variable along the coast as is the parallel threat of property erosion. This longshore variability results from the patterns of nearshore currents that assist the waves in cutting back the beach.

Nearshore currents and sediment transport

Waves reaching the coast generate currents in the nearshore zone that are important to sand movements on the beach and thus

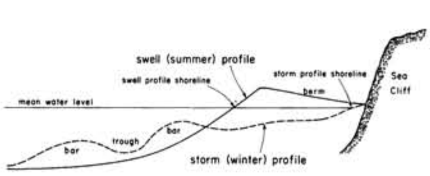

Figure 6. General pattern of seasonal changes in beach profiles associated with parallel variations in wave energies. From Komar (1976).

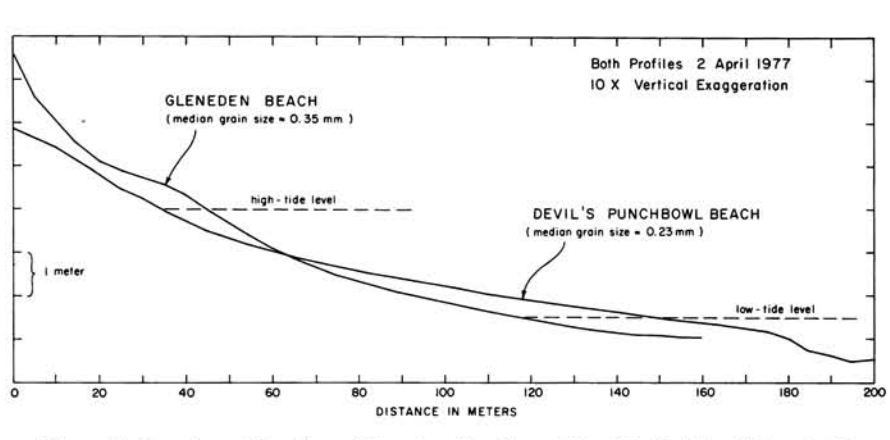

Figure 7. Beach profiles from Gleneden Beach and Devil's Puchbowl Beach (Otter Rock), Oregon, illustrating that coarser-sand beach (Gleneden) is steeper. From Aguilar and Komar (1978).

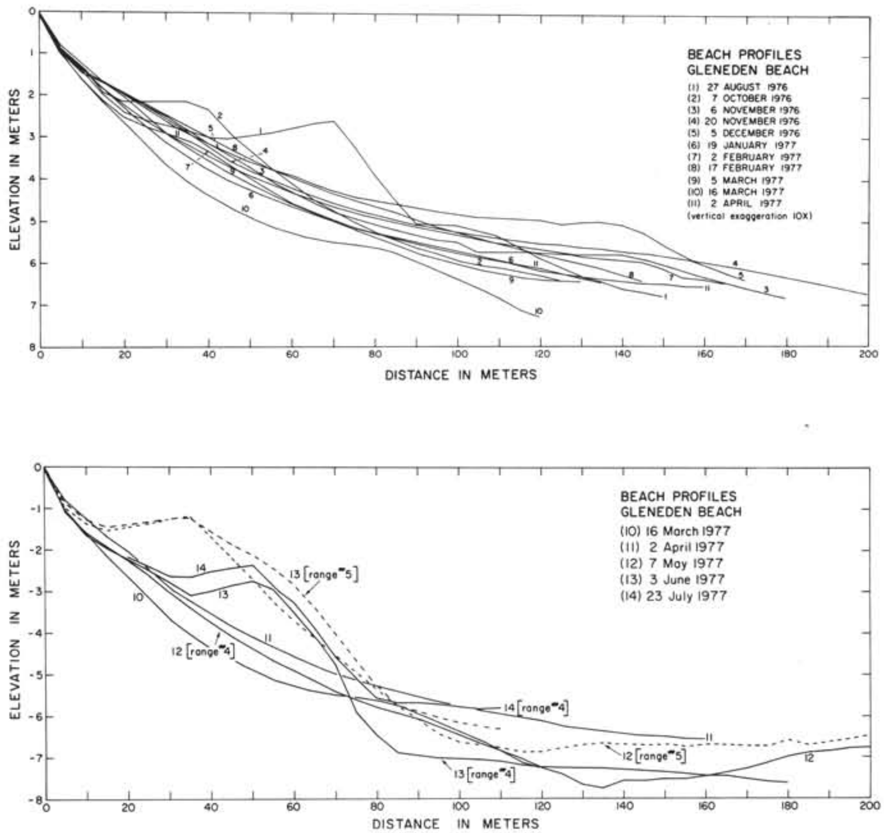

Figure 8. Series of beach profiles obtained at Gleneden Beach, Oregon, illustrating seasonal variations for Oregon coast beaches as shown schematically in Figure 7. From Aguilar-Tunon and Komar (1978).

deeper water and a steeper but more uniform beach slope. The rips move sand offshore and thereby tend to erode crescent-shaped embayments into the beach berm. Aerial views of the coast typically show beaches that are extremely irregular: a series of rip embayments of various sizes together with troughs cut by the longshore currents and rip currents (Figure 10). At times these rip-current embayments extend across the entire width of the beach and begin to cut into foredunes and sea cliffs. Such rip embayments have played a major role in property losses due to erosion. Although rip embayments seldom produce much property erosion on their own, they have the effect of eliminating the buffer protection of the beach berm. When a storm occurs, the waves are able to pass through the deep water of the rip embayment, not breaking until they reach the properties. Thus, rip embayments can control the center of attack by storm waves. The resulting erosion is commonly limited in longshore extent to only 100 or 200 yd, the longshore span of a rip embayment that reaches the foredunes or sea cliff (Figure 11).

When waves break at an angle to the beach, they generate a current that primarily flows parallel to the shoreline, although even then seaward-flowing rips may be present. This longshore current, together with the waves, produces a transport of sand along the beach, a sand movement that is known as "littoral drift." This is more than a local rearrangement of the beach sand with accompanying topography changes as produced by rip currents and the cell circulation. Instead, the littoral drift may involve along-coast movements that displace sand by many miles.

On Oregon beaches, the waves tend to arrive from the southwest during the winter and from the northwest during the summer (corresponding to changes in wind directions). As a result, there is a seasonal reversal in

to erosion processes. These wave-generated currents are independent of ocean currents that exist farther offshore, since those deep-ocean flows do not extend into the very shallow waters of the nearshore.

Most of the time, waves along the Oregon coast approach the beaches with their crests nearly parallel with the shoreline. Under such circumstances, the nearshore currents take the form of a cell circulation, the most prominent part of which are the seaward-flowing rip currents (Figure 9). The rip currents are fed by longshore currents flowing roughly parallel to shore, but they extend along only a short stretch of beach. The currents of this cell circulation are able to move sediments and so affect beach morphology. The longshore currents hollow out troughs into the beach that are generally increasing in width and depth as a rip current is approached. Rip currents can be very strong, cutting through the offshore bars to produce

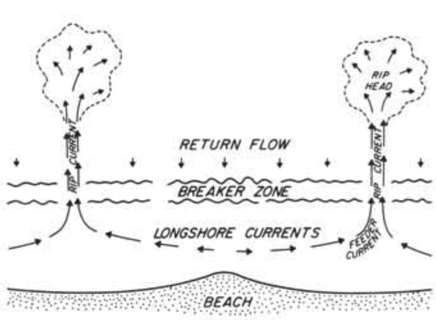

Figure 9. The nearshore cell circulation, consisting of rip currents that flow seaward and longshore currents that feed water to the rip currents.

Figure 10. Beach along Nestucca Spit, photographed during low tide, showing troughs and embayments eroded by longshore currents and rip currents.

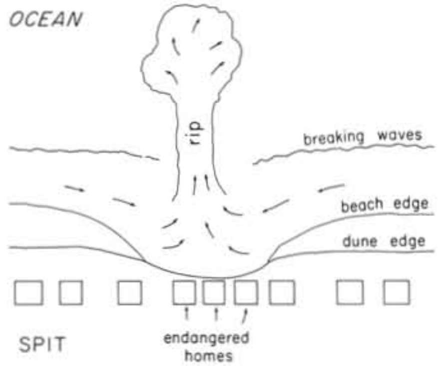

Figure 11. Schematic diagram illustrating how rip currents erode embayments that can cut through the beach and locally threaten properties.

the direction of littoral drift—north in the winter, south during the summer. The net littoral drift is the difference between these north and southward sand movements. Along most of the Oregon coast, this net drift is essentially zero, at least if averaged over a number of years. This is demonstrated by the absence of continuous accumulations of sand on one side of jetties or rocky headlands, with erosion on what would be the downdrift side (Komar, Lizarraga-Arciniega, and others, 1976).

Patterns of sand accumulation and erosion on opposite sides of jetties (Figure 12A) are found on many coasts where the net littoral drift is not zero; for example, along the shores of southern California and most of the east coast of the United States. In those areas, erosion in the downdrift directions from jetties

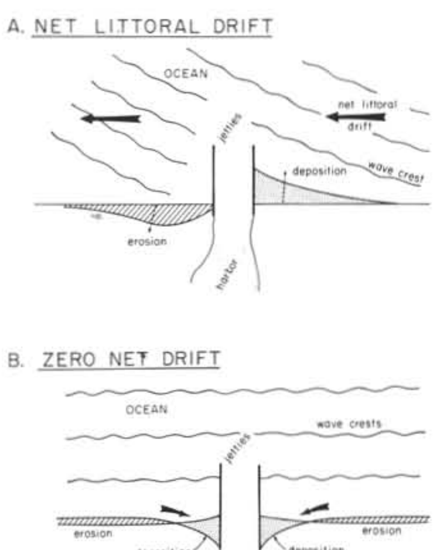

Figure 12. Patterns of sand accumulation around jetties, contrasting condition where jetties block a net littoral drift with condition where there is no net littoral drift. Jetties on the Oregon coast correspond to the latter condition.

has caused major problems and considerable losses of property (Komar, 1976, 1983b). In contrast, when jetties have been built on the Oregon coast, sand has accumulated on both their north and their south sides. This pattern is diagrammed schematically in Figure 12B and is illustrated specifically by the Yaquina Bay jetties in Figure 13. In the case of the Yaquina Bay jetties, more sand accumulated on the south than on the north, but this was due to the oblique orientation of the jetties to the overall trend of the coastline and because the pre-jetty shoreline curved significantly in toward the bay. More significant is that sand accumulated both north and south of the jetties until the embayments between the jetties and the pre-jetty shoreline filled and an equilibrium shoreline developed. Subsequent to achieving equilibrium, there has been almost no change in the shoreline configuration. The sand that accumulated adjacent to the jetties was derived from erosion of the beaches more distant from the jetties, so an overall symmetrical pattern emerged, one that is significantly different from the asymmetrical pattern found on coasts where there is a large net littoral drift (Figures 12A versus 12B). This reduces the potential for major erosion and property losses due to the construction of jetties on the Oregon coast, at least in comparison with other coasts where there is a large net littoral drift. However, one severe erosion problem did occur on the Oregon coast in direct response to jetty construction: the events that led to the destruction of the town of Bayocean (discussed below).

The pocket-beach nature of the Oregon coast and sources of nearshore sands

The ultimate cause of the zero net littoral drift of sand along the Oregon coast is that beaches are contained between rocky headlands, in effect forming pocket beaches (Figure 1). The headlands are large and extend to sufficiently deep water to prevent beach sand from passing around them. Therefore, the sand within each pocket beach is isolated. Sand may move north and south within a pocket due to the seasonality of the wind and wave directions, but the long-term net movement must be zero. Each of these pocket beaches on the Oregon coast can be thought of as a littoral cell. This is a useful concept in considering sources and losses of sediments on the beach, the so-called budget of littoral sediments. As will be discussed later, there are even contrasting patterns and magnitudes of erosion from cell to cell, particularly the erosion of sea cliffs.

The one beach on the Oregon coast that does not fit this pattern of a zero-drift pocket and self-contained littoral cell is the shoreline that extends south from the Columbia River past Seaside to Tillamook Head. This is the Clatsop Plains area, formed by the accumulation of sand derived from the Columbia

Figure 13. Shoreline changes at Yaquina Bay jetties, 1830 (representing pre-jetty configuration) to 1974, and photo of September 5, 1974, status. Sand accumulated both north and south, but volume to south is greater because the embayment created between the constructed jetty and the pre-jetty shoreline was larger; also due to oblique orientation of jetties compared with trend of shoreline. From Komar, Lizarraga-Arciniega, and others (1976).

River, part of which moves southward until it is blocked by Tillamook Head. However, the bulk of sand derived from the Columbia River moves northward along the coast of Washington. The quantities of this northward sand transport can be only roughly estimated, but the primary evidence for this sand supply is that many of the beaches along the southern half of the Washington coast are growing (Phipps and Smith, 1978). The highest rates of beach growth tend to be in the south, closest to the Columbia River, decreasing to the north until, beyond Copalis Head, net erosion prevails.

On many coastlines, sand spits grow in the direction of the net littoral drift. The Long Beach Peninsula extends northward from the Columbia River and likely reflects the net sand movement along the Washington coast. It is unclear whether this northward growth has continued within historic times, since there have been many cycles of growth and erosion at the tip of the Peninsula. There are several sand spits along the northern coast of Oregon, some pointing north, while others point to the south (Figure 1). Those spits are located within the beach cells where zero net littoral drift prevails, and their directions do not provide testimony as to net longshore sand movements.

In view of the pocket-beach nature of the Oregon coast, the question arises as to the sources of beach sand contained within those littoral cells. These sources are reflected in the small quantities of heavy minerals contained within the beach sand. On the Oregon coast, the beach sand generally consists of grains of quartz and feldspar minerals. Those particles are transparent or a light tan, and this is what governs the color of most beaches. However, the sands also contain small fractions of heavy minerals that are black, pink, various shades of green, and other colors. These grains are readily apparent as specks in a handful of beach sand and are sometimes concentrated by the waves into black-sand placer deposits on the beaches. Of importance is that these heavy minerals are indicative of the rocks they came from and in many cases can be traced back to specific rocks and therefore geographical sources. That is the case for the heavy minerals in the sands of the Oregon coast. Most distinctive are the minerals derived from the Klamath Mountains: a variety of ancient metamorphosed rocks is found in those mountains of southern Oregon and northern California. As shown in the diagram of Figure 14, sands derived from the Klamath Mountains contain such minerals as glaucophane, staurolite, epidote, zircon, hornblende, hypersthene, and the distinctive pink garnet that, in particular, can often be seen concentrated on the beach. In contrast, the rivers that drain the Coast Range transport sand containing almost exclusively two heavy minerals: dark-green augite and a small amount of brown hornblende (Figure 14). Augite comes from volcanic rocks and is contributed to the rivers by erosion of the ancient sea-floor rocks uplifted into the Coast Range. With the sand of the Columbia River comes a diversity of heavy minerals because the river drains a vast area that contains many types of rocks (Figure 14).

The presence of sand derived from the Klamath Mountains in beaches along almost the entire length of the Oregon coast is at first surprising—in view of the many headlands that prevent any longshore sand transport for that distance. However, thousands of years ago, during the maximum development of glaciers, the sea level was considerably lower, the shoreline was then on what is now the continental shelf, many miles to the west of its present position, and the beaches were backed by a smooth coastal plain. At that time, sand derived from rivers draining the Klamath Mountains could move freely northward as littoral drift without being blocked by headlands. Studies of heavy minerals contained within continental-shelf sands demonstrate that this was indeed the case (Scheidegger and others, 1971): the metamorphic minerals from the Klamaths can be found in the shelf sands nearly as far north as the Columbia River. As the Klamath-derived sand moved north, additional sand was contributed to the beaches by rivers draining the Coast Range, so there is progressively more augite and a smaller proportion of metamorphic minerals from the Klamaths in these beach sands. The Columbia River was a large source of sediment, but most of that sand moved to the north and dominates the mineralogy of ancient beach sands found on the Washington continental shelf. Some Columbia River sand did move south along the Oregon beaches during lowered sea levels and mixed with the sand from the Klamath Mountains and the Coast Range.

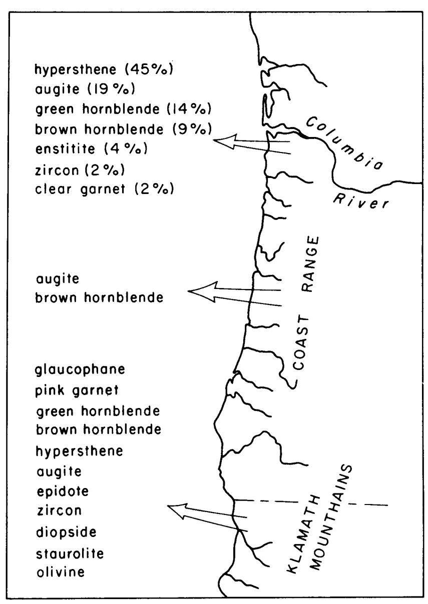

Figure 14. Principal sources of sand to Northwest beaches are the Columbia River and rivers draining the Coast Range and the Klamath Mountains. Each source supplies different suites of heavy minerals to beach and estuarine sands. From Clemens and Komar (1988b).

Therefore, the absence of headlands during lowered sea levels permitted an along-coast mixing of sands derived from multiple sources, principally from the Klamath Mountain metamorphics, the Coast-Range volcanics, and the Columbia River sands. Varying with the location along this former shoreline of the Oregon coast, the beach consisted of various proportions of mineral grains from those sources. Although a portion of the beach sand was left behind during the rapid rise in sea level and now can be found on the continental shelf, some of it migrated landward with the transgressing shoreline. The beaches would have been low in relief so that storm waves were able to wash over them, transporting sand from the ocean shores to the landward sides of the beaches and thereby producing the migration. Additional sand was contributed by the various river sources and from sediments eroded from the coastal plain.

About 5,000-7,000 years ago, the rate of rise in sea level decreased as the water approached its present level. Just about at that time, the beaches of Oregon came under the influence of headlands that segmented the formerly continuous shoreline. At some stage several thousand years ago, the headlands extended into sufficiently deep water to hinder further along-coast transport of the beach sands. This is shown by a study of the mineralogy of sand found on the present-day beaches (Clemens and Komar, 1988a,b). The pattern of along-coast mixing of sand from the various sources, established during lowered sea levels, is still partly preserved within the series of pocket beaches now separated by headlands. Therefore, one can still find minerals derived from the Klamath Mountains in virtually all of the beaches along the Oregon coast, even though it is certain that the sand can no longer pass around the many headlands that separate those beaches from the Klamath Mountains. In most cases, the Klamath-derived sand could have reached the modern beach only by along-coast mixing during lowered sea levels and subsequent onshore transport with the rise of the sea. However, there has been some modification of the beach-sand mineralogy from that along-coast mixing pattern, as local sources have contributed sand to the beaches during the last few thousand years. Such beach-sand sources include eroding sea-cliffs and some sand from the rivers and streams entering the isolated pocket beaches.

There can be distinct changes in beach-sand mineralogies on opposite sides of headlands, that is, within adjacent but isolated pocket beaches or littoral cells (Clemens and Komar, 1988a,b). One such case is found at Cascade Head north of Lincoln City, continuing at Cape Foulweather farther south. To the north of Cascade Head, the beach sand is rich in augite, which either came from the local rivers and streams draining the Coast Range or from sea-cliff erosion that cuts into alluvium derived from that same volcanic source. In contrast, to the south of Cascade Head, the augite content of the beach sand is much reduced. Sea-cliff erosion is of obvious importance there, but these cliffs are cut into a marine terrace that contains sands of uplifted ancient beaches and dunes. Analyses of the mineralogy of those terrace sands indicate that they are also composed of mixtures of Klamath Mountain, Coast Range, and Columbia River sands (Clemens and Komar, 1988a). Apparently these terrace deposits also record an along-coast mixing of sediments at lowered sea levels, a mixing that was preserved much as it has been on the modern beaches. This conclusion has an unfortunate aspect in that it makes it virtually impossible to distinguish what portion of the sand on the modern beach in that area has been contributed by recent cliff erosion and what portion moved onshore during the last rise in sea level. At any rate, the change in beach-sand mineralogy on opposite sides of Cascade Head demonstrates the effectiveness of that headland in isolating the adjacent pocket beaches and shows that recent contributions to the beaches have been sufficient to alter the pattern established by along-coast mixing during lowered sea levels.

A still more dramatic change in the beach sand occurs at Tillamook Head, south of Seaside (Figure 15) (Clemens and Komar, 1988a,b). North of this headland, the beach sand is derived almost entirely from the Columbia River, and the abundant supply of sand from that large river has built the shoreline out significantly within historic times. South of the headland, the beach sand is abundant in augite, again indicating a Coast Range source from local rivers or cliff erosion. This beach sand also contains small amounts of Klamath Mountain minerals, the northernmost instance where the relict pattern of along-coast mixing during lowered sea levels can be found preserved in the modern beaches. There is some Columbia River sand in this beach to the south of Tillamook Head, but it got there by mixing southward with sands from the other sources during lowered sea level and then migrating onshore. That Columbia-derived sand has been on the beach for thousands of years, whereas to the north of the headland the beach sand came from the Columbia within the last century or two. This contrasting history of the beach sands is also indicated by the degree of rounding of the individual grains as shown in Figure 15. North of the headland, the grains are fresh in appearance

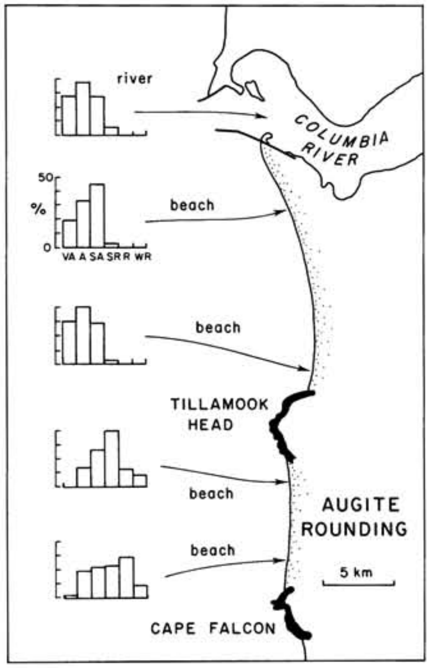

Figure 15. Diagram showing changes in degree of rounding of beach sand on opposite sides of Tillamook Head. VA = very angular, A = angular, SA = subangular, SR = subrounded, R = rounded, and WR = well rounded). After Clemens and Komar (1988a).

and angular, attesting to their recent arrival from the Columbia: the grinding action of the surf has not had sufficient time to abrade and round the grains. To the south of the headland, the grains are much rounder: their sharp edges have been worn away during thousands of years of movement beneath the swash of waves on the beach.

During low stands of sea level, the coastal rivers were able to cut down their valleys. When the water rose at the end of the ice age, these valleys were drowned and developed into estuaries. These estuaries are important, serving as harbors and the centers of many of our coastal communities. They are also environments of significant fisheries and, as will be discussed here, play a central role in sediment movements on the coast that govern contributions of sand to the beaches.

An estuary is a zone of complex mixing of fresh water from the river with the ocean's salt water. The fresh water is less dense and therefore tends to flow over the top of the sea water. At times, much of the fresh water from the river flows through the entire estuary and enters the ocean before it finally mixes with the underlying sea water. In such a case, the lens of salt water at depth within the estuary has a net flow from the ocean into the estuary. This situation is found in many Northwest estuaries and is significant, since it is one mechanism that transports sediment from the ocean into the estuary and inhibits the river sands from reaching the ocean beaches.

The restriction of sand movement through Northwest estuaries was first demonstrated in a study of the sediments within Yaquina Bay (Kulm and Byrne, 1966). Similar to the other rivers draining the Coast Range, the Yaquina River transports sand containing augite as its principal heavy mineral. This contrasts with the beach sand outside of the Bay, which contains a large variety of minerals, including the metamorphic minerals that were derived from the Klamath Mountains. In addition, some of the quartz and feldspar grains on the beach are coated with red iron oxide. These are probably grains contributed to the beach from sea-cliff erosion of the marine terraces; such coated grains are not found in the Yaquina River. These differences make it possible to trace the movement of the river and beach sands entering the estuary. The result is summarized in Figure 16, where it is seen that the river sand (fluviatile) forms 100 percent of the estuarine sediment in only the landward portion of the Bay. Marine sand has been carried into the Bay through the inlet and dominates the estuarine sediments near the mouth. Much of the Bay is a zone where the river and marine sands are mixed in varying proportions.

The results indicate that Yaquina Bay is slowly being filled with sediment—from the direction of the land by fluviatile sands and from the ocean side by marine sands. This has also been shown for Alsea Bay, where drilling through the sediments indicates that the bay began to fill immediately after the formation of the estuary with the last rise in sea level and is continuing to fill (Peterson and others, 1982, 1984b). Becoming filled with sediments is generally the fate of estuaries. Having developed by the drowning of river valleys at the end of the ice age, they represent an environment that is out of equilibrium. As a result, estuaries tend to fill until reduced to a river channel that is able to transport all of its sediments to the ocean. Such a development involves thousands of years, so we should not view our estuaries as ephemeral features.

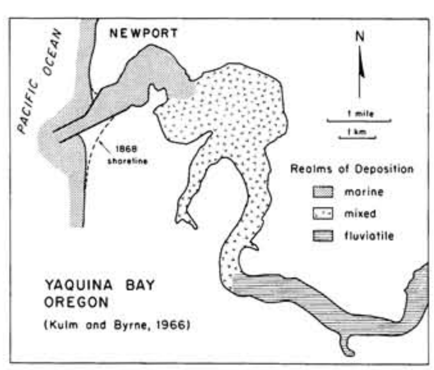

Figure 16. Sediment patterns within Yaquina Bay, illustrating the mixing of marine sands carried into estuary by tidal flows and fluvial sands from the river. After Kulm and Byrne (1966).

Another implication of the results in Figure 16 is that little if any sand from the Yaquina River is presently reaching the ocean beach. This conclusion applies only to sand-size grains. The fine clays that remain in suspension in the water are carried into the ocean, evident by the brown plumes that emanate from the inlet during river floods. Most of the major coastal rivers are separated from the ocean by large estuaries and are not likely to be significant contributors of sand to the modern beaches. This in part explains why many of the Oregon beaches have relatively small volumes of sand and why their mineralogies still reflect the along-coast mixing of sand sources during low stands of sea level rather than more recent contributions.

Such patterns of sand deposition have been shown to occur in other major estuaries of the Northwest (Scheidegger and Phipps, 1976; Peterson and others, 1984a). However, a study of the small Sixes River of Oregon, which does not really have an estuary, indicates that it supplies sand to the adjacent beach, although the amounts would be minor given the small size of that river (Boggs, 1969; Boggs and Jones, 1976). In general, the major rivers have sufficiently large estuaries to make it doubtful whether much, if any, of the river sand reaches the adjacent beaches. The one clear exception to this is the Columbia River, which transports more than 100 times as much sand as the next largest river (the Umpqua) and on the order of 1,000 times as much sand as other coastal rivers (Clemens and Komar, 1988a).

CASE STUDIES OF SAND SPIT EROSION

The most dramatic occurrences of erosion on the Oregon coast have centered on the sand spits. The causative factors have ranged from jetty construction at Bayocean Spit, to natural processes of waves and currents at Siletz and Nestucca Spits, to extreme examples of erosion processes at Alsea and Netarts Spits initiated during the 1982-83 El Niño.

Jetty construction and the erosion of Bayocean Spit

The story of Bayocean Spit is of particular interest in that it provides the earliest example on the Oregon coast of a failed attempt at a major development and also of the erosive impacts that are associated with jetty construction (Terich and Komar, 1974; Komar and Terich, 1976). The San Francisco realtor T.B. Potter was attracted to Tillamook Bay during a fishing trip in 1906 and vowed to build the "Atlantic City of the Pacific Coast" on the spit separating the bay from the ocean. His vision soon took form with the construction of an elegant hotel, a natatorium (housing a heated swimming pool with artificial surf), a number of permanent homes, and a "tent city" for summer visitors. The downtown contained a grocery, bowling alley, and agate shop. However, the development soon ran into economic problems as lots did not sell at the hoped-for rate, primarily due to the inaccessibility of the area and delays in construction of the railroad from Portland.

But the chief threat came from erosion caused by jetty construction in 1914-17 at the mouth of Tillamook Bay (Figure 17). Due to economic constraints, only a north jetty was completed at that time (the south jetty was not built until 1974), and this turned out to be critical to the magnitude of the resulting erosion. The overall pattern of sand movement and shoreline changes was similar to that depicted schematically in Figure 12B, made more complex by the fact that only one jetty was constructed. Sand quickly accumulated north of the jetty (Figure 17), with the shoreline building out. At the same time, sand also accumulated to the south but formed a shoal within the mouth of the inlet, thus greatly increasing the hazards to navigation. The sand that formed the shoal was derived from erosion along the length of Bayocean Spit. It is likely that some of the sand brought to the shoal was carried into the bay and some perhaps to the offshore, so that erosion of Bayocean Spit continued for many years rather than reaching a new equilibrium as is possible where two jetties are constructed (Figure 12B).

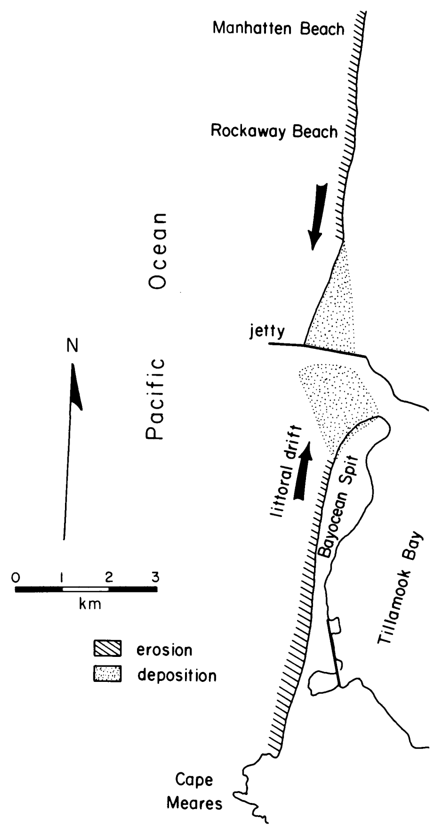

Figure 17. Schematic diagram illustrating patterns of erosion and accretion in response to construction of the north jetty at the inlet to Tillamook Bay. Sand that came from erosion along the length of Bayocean Spit accumulated to form an extensive shoal at the mouth of the inlet.

The erosion of Bayocean was most rapid during the 1930s and 1940s following reconstruction and lengthening of the north jetty. The ocean edge of the spit retreated, dropping houses, the natatorium (see cover photo, upper left), and finally the hotel into the surf. A storm during November 1952 brought the final demise of the development, breaching the spit at its narrowest point. This breach was diked by the Corps of Engineers in 1956, rejoining what had become an island to the mainland. All that remains of Potter's development is bare land with a few slabs of concrete foundations that now litter the beach.

Natural processes and the erosion of Siletz and Nestucca Spits

The erosion of Siletz and Nestucca Spits provides examples of the impact of natural processes: the combined effects of rip currents, storm waves, and elevated water levels (Komar and Rea, 1976; Komar and McKinney, 1977; Komar, 1978, 1983a). The development of Siletz Spit began in the 1960s with the construction of a number of homes, many within the foredunes immediately backing the beach. The first major episode of erosion leading to property losses occurred during the winter of 1972-73. One house under construction was lost (see cover photo, lower right). Others ended up on promontories extending into the surf zone, when riprap was first installed along their seaward fronts and then on their flanks, as adjacent empty lots continued to erode. The main factor in that erosion episode was the occurrence of major storm waves: the 23-ft significant wave heights of December 1972 in the microseismometer record of Figure 4. However, the erosion was limited to only a small portion of the spit, determined by the presence of a rip current that had hollowed out an embayment in the beach, so that waves were able to reach the foredunes and houses (Figure 18).

A series of aerial photographs of Siletz Spit revealed the repeated occurrence of such erosion events over the years. In general, during any one winter, the erosion would occur in only one or two locations determined by the largest rip-current embayments. In subsequent winters, the erosion would shift to other areas, as the rip currents changed positions. (We do not know what controls the locations of rip currents and therefore cannot predict where the erosion will occur.) In the meantime, earlier "bites" taken out of the foredunes by rip currents and storm waves would fill in with drift logs, which in turn captured wind-blown sands, so the dunes quickly formed again. This cycle of dune erosion and reconstruction occurred repeatedly on Siletz Spit, with no measurable long-

Figure 18. Rip currents cutting embayments through beach and reaching development on Siletz Spit during December 1972. Large embayment seen in upper photograph was center of property losses photographed in cover photo, lower right.

term net retreat of the seaward edge of the foredunes on the spit.

The principal mistake made in developing Siletz Spit was to build homes in this zone of foredunes that is susceptible to periodic erosion. We quickly became aware of this during the erosion of 1972-73 (cover photo, lower right): the erosion exposed drift logs within the heart of the spit, often beneath homes built in the 1960s—drift logs that had been cut by saws. What clearer indication could one have of the ephemeral nature of the sites where these homes had been built?

Siletz Spit has repeatedly eroded during subsequent winters, but each time more riprap was added, so that the properties are now reasonably secure. Lots lost to erosion have been filled with beach sand and leased again for development.

Large storm waves combined with high spring tides during February 1978 to cause extensive erosion in many areas of the Oregon coast (Komar, 1978). The greatest impact occurred along Nestucca Spit on the northern Oregon coast, where an uninhabited area of the spit was breached and foredune erosion threatened a new development where houses were still under construction (Figure 19 and cover photo, center). Storm waves again combined with rip-current embayments to control the zones of maximum erosion along the spit as well as to determine the area of breaching. However, of particular importance to the erosion was the simultaneous occurrence of high perigean spring tides plus a storm surge that raised water levels by some 8-9 in. above predicted tide levels. Spring tides occur when the Moon, Earth, and Sun line up so that the gravitational forces causing the tide superim-

Figure 19. Upper photo: Riprap placed to protect homes under construction at Kiwanda Shores on Nestucca Spit in response to erosion during February 1978. Lower photo: Subsequent accumulation of dune sands, completely covering riprap and becoming a problem for homes (1988 photo).

pose, producing the highest monthly tides. A perigean spring tide occurs when the Moon comes closest to the Earth in its eliptical orbit, so that the tide-producing force is still greater than during normal spring tides. Typical spring tides on the Oregon coast reach +9 ft MLLW (= "mean lower low water"—the average of the lowest daily tides, which is taken as the 0-reference tidal elevation), whereas perigean spring tides achieve +10 ft MLLW . At the time of the February 1978 storm that eroded Nestucca Spit, measured high tides reached +10.2 ft MLLW—unusually high tides for the Oregon coast and substantially higher than the tides during the December 1972 erosion of Siletz Spit.

It was this combination—high perigean spring tides with a significant storm surge, exceptionally energetic storm waves, and the development of a major rip-current embayment that by chance focused the erosion along the thinner section of the spit—that resulted in the unusual occurrence of breaching at Nestucca Spit. The only other spit breaching known to have occurred during historic times was at Bayocean Spit, and that breach was due to jetty construction rather than natural causes. On spits and barrier islands of the east and Gulf coasts of the United States, there are frequent occurrences of breaching and washovers, due to the rise in sea level with respect to the land. However, the Northwest coast is rising tectonically, so there is minimal transgression of the sea over the land, and this probably accounts for the rarity of spit breaching here. It took the unusual circumstances of the February 1978 storm to produce a breach.

When the storm struck in February 1978, a development of new houses was under construction on the foredunes at Kiwanda Beach at the north end of Nestucca Spit (Figure 19, upper). Like the erosion of Siletz Spit, drift logs were exposed within the eroding dunes, some of which had been sawed. However, these logs were more rotten than those found within Siletz Spit, suggesting that erosion episodes on Nestucca Spit are less frequent. The lower frequency of erosion occurrences at Nestucca Spit is probably due to the fact that the beach sand here is finer grained than at Siletz (recalling from the discussion earlier that coarser-sand beaches respond more rapidly and to a greater degree to storm-wave conditions). Nestucca Spit began to mend during the summer following its erosion. Similar to the dune reformation on Siletz Spit, drift logs accumulated within the breach and helped to trap wind-blown sand. So much sand has returned to the beach fronting the Kiwanda Beach housing development that the masses of riprap are now buried and the overabundance of sand has become a problem (Figure 19, lower).

The 1982-83 El Niño—an unusual erosion event

A decade ago, an El Niño was thought to involve only a shift in currents and a warming of ocean waters to the west of South America. Its occurrence was primarily of interest because an El Niño caused the mass killing of fish off the coast of Peru. No one imagined that an El Niño had wide-ranging consequences, including that of playing a major role in beach erosion along the west coast of the United States. This awareness came during the El Niño of 1982-83, an event of unusual magnitude, when erosion problems were experienced along the shores of California and Oregon. The natural processes usually involved in beach erosion also played a role during the 1982-83 El Niño, but generally at much greater intensities than normal. In addition, there were unusual effects that enhanced the overall erosion problems and caused them to continue well beyond 1982-83.

It once was thought that the onset of El Niño off Peru was caused by the cessation of local coastal winds that produce upwelling. This view changed when it was demonstrated that these local winds do not necessarily diminish during an El Niño, but that it is instead the breakdown of the equatorial trade winds in the central and western Pacific that triggers an El Niño. During normal periods of strong southeast trades, there is a sea-level setup in the western equatorial Pacific with an overall east-to-west upward slope of the sea surface along the equator. The same effect is obtained when you blow steadily across a cup of coffee: the surface of the coffee becomes highest on the side away from you. If you stop blowing, the coffee surges back and runs up your side of the cup. The process is similar in the ocean, when the trade winds stop blowing during an El Niño. The potential energy of the sloping water surface is released, and it is this release that produces the eastward flow of warm water along the equator toward the coast of Peru where it kills fish that are not adapted to warm water. In association with this warm-water movement eastward along the equator, a wavelike bulge in sea level occurs. The Coriolis force, which results from the rotation of the Earth on its axis, causes currents to turn to the right in the northern hemisphere and to the left in the southern hemisphere. Since this released water during an El Niño flows predominantly eastward along the equator, the Coriolis force acts to confine the wave to the equatorial zone, constantly turning it in toward the equator. This prevents the dissipation of the sea-level high by expansion to the north and south away from the equator. The eastward progress of the sea-level wave can be monitored at tide gauges located on islands near the equator (Wyrtki, 1984). As discussed earlier, measurements from a tide gauge can be averaged so as to remove the tidal fluctuations, yielding the mean sea level for that period of time. Sea-level variations at islands along the equator during the 1982-83 El Niño are shown in Figure 20. From these tide-gauge records one can easily envision the passage of the released sea-level wave as it traveled eastward across the Pacific. Its crest appears to have passed Fanning Island south of Hawaii in late August, Santa Cruz in the Galapagos at the end of the year,

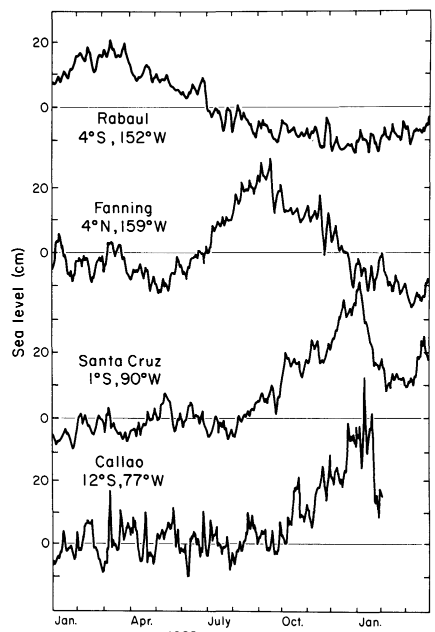

Figure 20. Sea-level "wave" during the 1982-83 El Niño measured at a sequence of islands from west to east near the equator, and finally at Callao on the coast of Peru. After Wyrtki (1984).

and reached Callao on the coast of Peru in January 1983. Water-level changes associated with these sea-level waves during an El Niño are very large, as Figure 20 shows. They typically involve variations up to 50 cm (20 in.) and take place within a relatively short period of time, 4-6 months. Translated into an annual variation, this is equivalent to a rate of approximately 1,000 mm/year, far in excess of the 1-2 mm/year global rise in sea level that is caused by the melting of glaciers.

With its arrival on the coast of South America, the sea-level wave splits, and the separated parts respectively move north and south along the coast. Now the wave is held by the inclination of the continental shelf and slope, by the combined effects of wave refraction over the slope and the Coriolis force. This again prevents the sea-level high from flowing out to sea and dissipating. Analyses of tide-gauge records along the coast have demonstrated that the sea-level waves can travel as far north as Alaska (Enfield and Allen, 1980). The analyses have also shown that as the sea-level wave travels northward, it looses relatively little height at the coastline itself. The Coriolis force increases in strength at higher latitudes, so the wave hugs the coast more tightly and thereby maintains its height, even though it may loose some of its energy. The wave travels at a rate of about 50 mi per day and thus quickly reaches California and Oregon following its inception at the equator. The water-level changes associated with these shelf-trapped sea-level waves are an important factor in beach erosion along the west coast of North America during an El Niño.

In summary, one aspect of an El Niño is the generation of large sea-level variations that take the form of a wave; the wave first moves eastward along the equator and then splits into poleward-propagating waves when it reaches the eastern margin of the Pacific Ocean. These basin-wide responses involve several months of wave travel, and at any given coastal site the sea-level wave may significantly raise water levels for several months.

Figure 21 shows the monthly mean-sea levels measured by the tide gauge in Yaquina Bay during the 1982-83 El Niño (Huyer and others, 1983; Komar, 1986). The sea level reached a maximum during February 1983, nearly 60 cm (24 in.) higher than the mean water surface in May 1982, nine months earlier. The thin solid line in the figure follows the ten-year means for the seasonal variations, and the dashed lines give the previous maxima and minima measured in Yaquina Bay. These curves in part reflect the normal seasonal cycle of sea level produced by parallel variations in atmospheric pressures and water temperatures. However, it is apparent that the sea levels of 1982-83 were exceptional, reaching some 10-20 cm higher than previous maxima, about 35 cm (14 in.) above the average winter level. Much of this unusually

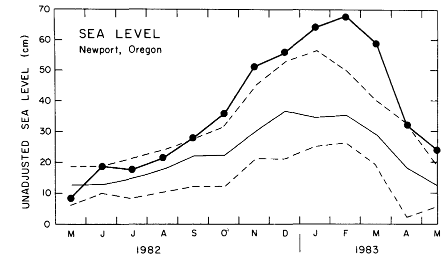

Figure 21. Monthly sea levels measured with tide gauge in Yaquina Bay. Record from 1982-83 El Niño year (dots) shows that water levels exceeded all previous records. Mean values given by solid line, previous maxima and minima by dashed lines. From Huyer and others (1983) and Komar (1986).

high sea level can be attributed to the effects of a coastally trapped sea-level wave generated by the El Niño.

Wave conditions on the Oregon coast were also exceptional during the 1982-83 El Niño (Komar, 1986). Figure 22 shows the daily measurements from the microseismometer at Newport, collected from August 1982 through April 1983. There were several storms that generated high-energy waves, three achieving breaker heights on the order of 20-25 ft.

The erosion which occurred on the Oregon coast during the 1982-83 El Niño was in response to these combined processes. The large storm waves that struck the coast arrived at the same time as sea level was approaching its maximum. High spring tides were also a factor. During the December 1982 storm, high tides reached +11.0 ft MLLW, 23 in. higher than the predicted level due to the raised sea level. The tides during the January 1983 storm were still more impressive, reaching +12.4 ft, 34 in. higher than predicted. This pattern continued during the February 1983 storm, when high tides up to +10.3 ft were measured, 17 in. above the predicted level. All of these high tides represent exceptional water elevations for the coast of Oregon.

As expected, the intense storm activity and high water levels during the winter of 1982-83 cut back the beaches of the Oregon coast. However, for a time the patterns of erosion were puzzling. There were numerous reports of erosion problems along the coast,

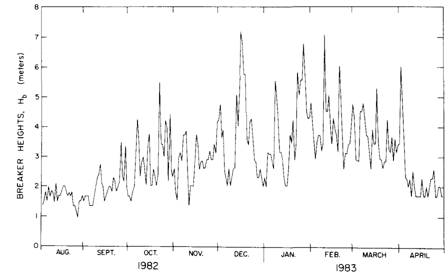

Figure 22. Wave breaker-height measurements from Newport during 1982-83 El Niño period. From Komar (1986).

yet beaches in other areas were building out. It took some time to determine what was happening.

As discussed earlier, the summer waves normally approach from the northwest, while the winter waves arrive from the southwest, so there is a seasonal reversal in sand transport directions along the beaches. Over the years there is something of an equilibrium between the north and south sand movements within any pocket, yielding a long-term zero net littoral drift. This equilibrium condition was upset during the 1982-83 El Niño due to the southward displacement of the storm systems. The waves approached the Oregon coast from a more southwesterly direction, and this together with the high wave energies of the storms caused an unusually large northward movement of sand within the beach cells (Figure 23). The resulting effect was one of sand erosion at the south end of each pocket beach and deposition at the north. This can be viewed as the reorientation of the pocket beaches to face the waves arriving from the southwest, or as any one headland acting like a jetty so that it blocks sand on its south and causes erosion to its immediate north.

This pattern is illustrated in Figure 24 for

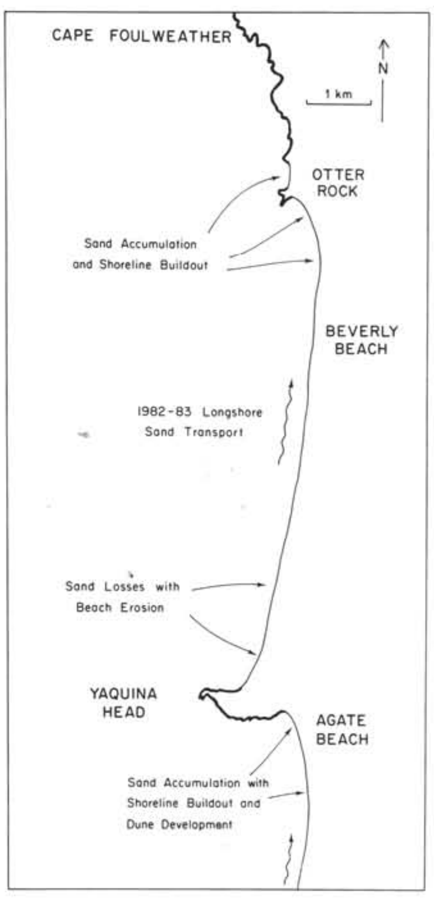

Figure 23. Patterns of beach erosion and accretion during 1982-83 El Niño, resulting from northward transport of sand within the littoral cell. From Komar (1986).

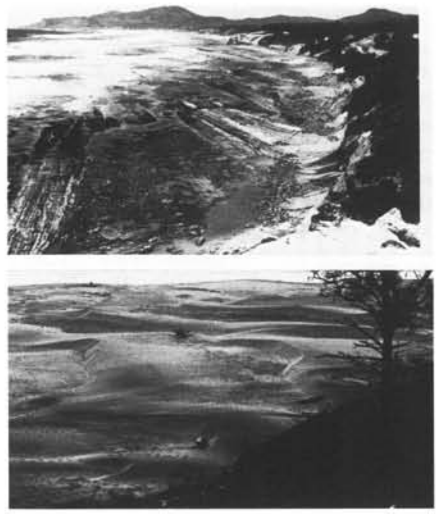

Figure 24. Beaches north and south of Yaquina Head during 1982-83 El Niño, with a total depletion of sand to the north (upper), while large quantities of sand accumulated to the south on Agate Beach (lower).

the beaches north and south of Yaquina Head. North of that headland, the beach eroded down to bed rock (Figure 24, upper), while south of it, at Agate Beach, so much sand accumulated that it formed a large field of dunes (Figure 24, lower). Those who had the misfortune to live north of the headlands, at the south ends of the pocket beaches, experienced some of the greatest beach and property losses along the coast. There, the beaches eroded back to a greater degree than during normal winters, the sand not only moving offshore to form bars but also northward along the shore. Having lost the buffering protection of the fronting beaches, properties north of headlands suffered the direct attack by storm waves, which in many areas resulted in considerable erosion losses.

The area that suffered the greatest erosion during the 1982-83 El Niño was Alsea Spit on the central Oregon coast (Komar, 1986). The erosion there was mainly in response to northward longshore movement of beach sand, a movement which deflected the inlet to Alsea Bay. Although the problem originated during the 1982-83 El Niño, the erosion continued for several years due to the disruption from normal conditions. During normal periods, the channel from Alsea Bay continues directly seaward beyond the inlet mouth, but during the 1982-83 El Niño this channel was deflected well to the north, as seen in the photograph of Figure 25. The inlet mouth itself migrated little; the deflection instead took place in the shallow offshore area. Apparent in this photograph is an underwater bar that extends from the south and is covered with breaking waves. It was the northward growth of this bar that diverted the channel from its normal course, the bar growth having occurred as a result of the

Figure 25. Deflection of channel leading into Alsea Bay by northward growth of longshore bar in response to storm waves related to 1982-83 El Niño and arriving from southwest. From Komar (1986).

northward sand transport during El Niño.

The erosion experienced on Alsea Spit, which continued for about three years, can be directly attributed to this northward deflection of the channel. The earliest property losses on the spit occurred during the winter of 1982-83 on the ocean side, well to the north of the inlet. The focus of this erosion was directly landward of where the channel turned seaward around the end of the northward-extending offshore bar. Erosion there appeared to be caused by the oversteepened beach profile leading into the deep channel and by direct wave attack: waves passing through this channel did not break over an offshore bar and therefore retained their full energy until they broke directly against the properties on the spit. The erosion continued for more than three years with more losses of property, as the deflected channel slowly migrated southward towards its former position. Figure 25 shows a photograph taken during July 1985, by which time significant migration had already taken place from the most northerly position of the opening during the winter of 1982-83. With this slow southward movement of the opening, the focus of maximum erosion on the spit similarly shifted south. In September 1985, there was an abrupt increase in the rate of erosion, as the focus was then on the unvegetated, low-lying tip of the spit seen in Figure 25. Within a couple of weeks, this tongue-extension of Alsea Spit completely eroded away. At the same time, the deep water of the offshore channel shifted landward, directly eroding the developed portion of the spit where it curves inward toward the inlet. Seven houses were threatened by this erosion, particularly one that was adjacent to an empty lot initially left unprotected (Figure 26).

The beach fronting Alsea Spit grew significantly during the summer of 1986, and the tongue of sand began to reform at the end of the spit. Erosion during the winter of 1986-87 was minimal, so that Alsea Spit and the inlet to the bay finally returned to the configurations that had prevailed for many years prior to the 1982-83 El Niño.

The effects of the 1982-83 El Niño persisted still longer in the erosion of Netarts

Figure 26. Erosion of Alsea Spit as a result of inlet deflection during 1982-83 El Niño. From Komar (1986).

Spit (Komar and others, 1988; Komar and Good, 1989). That erosion has been of particular concern in that its impact has been in Cape Lookout State Park, a popular recreation site. Netarts Spit forms most of the stretch of shore between the large Cape Lookout to the south and Cape Mears to the north (Figure 27). Erosion of Netarts Spit during historic times had been minimal. In the late 1960s, a seawall was constructed at the back of the beach in the park area. Its construction was not entirely a response to wave-erosion problems but in part to people walking on the dune face and causing renewed activity of sand movement by winds. Therefore, the sudden and dramatic erosion during the 1982-83 El Niño came as a surprise. Being one of the smallest of the littoral cells on the coast, the pocket beach within the Netarts cell underwent a marked reorientation due to the southwest approach of waves during the El Niño. This depleted the beach of sand immediately to the north of Cape Lookout, leading to erosion of the low-lying sea cliffs and sand dunes in that area. However, of more lasting significance is that much of the sand transported northward along the beach was apparently swept through the tidal inlet into Netarts Bay, and perhaps some to the offshore. This effectively removed the sand from the nearshore zone, leaving the beach depleted in sand volumes and thus less able to act as a buffer between park properties and storm-erosion processes. Because of this, erosion problems on Netarts Spit have been endemic in recent years and have continued even though the direct processes of the 1982-83 El Niño have ceased.

Figure 27. Netarts Spit and inlet to Netarts Bay with Cape Lookout in background, March 1978. Oregon State Highway Department photo.

The occurrence of rip currents and storm waves have been the chief agents of erosion on Netarts Spit. These cut back the beach in the park area so that much of it was covered by exposed cobbles rather than sand (Figure 28). The seawall was destroyed, so that erosion of park lands became substantial. The placement of riprap in order to prevent additional losses of park lands was considered. However, in subsequent winters the rip currents could be positioned in other areas along the spit, causing erosion there. The more fundamental problem is the depleted volume of sand on the beach. To solve this, State Parks officials have considered a beach nourishment project, the placement on the beach of sand brought in from some other location. Sand nourishment would restore the beach along its full length, both in its ability to act as a buffer and in its recreational uses. Possible sources of sand for such a nourishment project might come from the yearly dredging by the Corps of Engineers within Tillamook Bay or in the Columbia River. A more logical source would be from dredging sandy shoals in Netarts Bay in that this would in effect return sand to the beach which had been swept into the bay, some of it during the 1982-83 El Niño. An associated positive effect would be the restoration of the bay itself, which has undergone considerable shoaling. However, Netarts Bay contains many acres of protected wetlands and has the highest diversity of clam species of any Oregon estuary. Accordingly, dredging and sand removal would have to be balanced against the probable negative impacts of such operations in the bay.

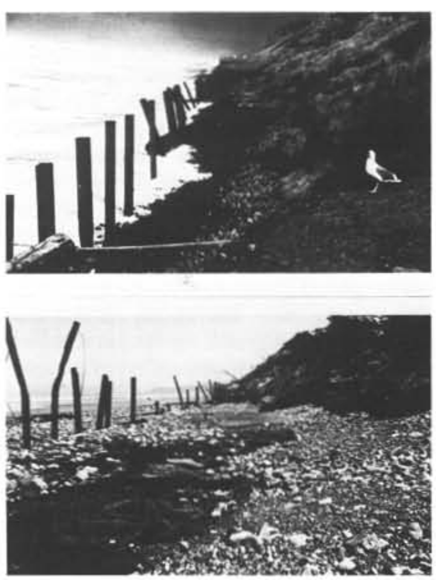

Figure 28. Progressive erosion of Cape Lookout State Park following the 1982-83 El Niño. (upper) Destruction of log bulkhead and initiation of dune erosion during October 1984. (lower) Erosion during winter of 1988, leaving a beach composed of cobbles and gravel rather than sand, and I-beams of log bulkhead at mid-beach. From Komar and others (1988).

PROCESSES AND PATTERNS OF SEA-CLIFF EROSION

The erosion of sea cliffs is a significant problem along many of the world's coastlines, including Oregon (cover photo, upper right). Most communities of the Oregon coast are built on uplifted marine terraces or on alluvial slopes emanating from the nearby Coast Range. These elevated lands are subject to erosion along their ocean margins with the formation of cliffs. State lands are also being lost as cliff erosion occurs in coastal parks and affects state highways.

Considering the extent and importance of sea-cliff erosion, it is surprising how few studies have focused on this problem, at least in comparison with beach-erosion problems and processes. Part of the reason for this is the inherent difficulty in accounting for the multitude of factors that can be involved in cliff erosion (Figure 29). One of the most problematic aspects is the cliff itself, its material composition and structure, the latter including bedding stratification (horizontal or dipping), and the presence of joints and faults. These factors are important in determining whether the cliff retreat takes the form of abrupt large-scale landsliding or the more continuous failure of small portions of the cliff face. The processes of cliff attack are also complex. The retreat may be primarily caused by groundwater seepage and direct rain wash, with the ocean waves acting only to remove the accumulating talus at the base of the cliff. In other locations, the waves play a more active role, directly attacking the cliff and cutting away its base.

Only limited study has been devoted specifically to cliff erosion along the Oregon coast. The earliest work examined the oc-

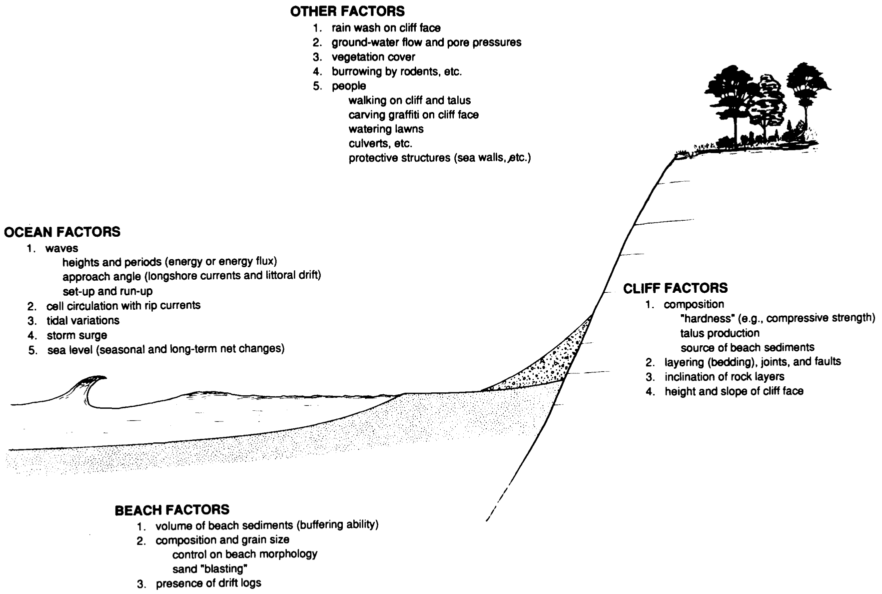

Figure 29. Schematic diagram illustrating the many factors and processes involved in sea-cliff erosion.

currence of major landslides and documented the importance of factors such as rainfall intensity and rock jointing and bedding (Byrne, 1963, 1964; North and Byrne, 1965). Little information is available on the long-term erosion rates of sea cliffs not affected by major landslides. Stembridge (1975) compared two sequences of aerial photographs (1939 and 1971) to estimate erosion rates, but his analysis was limited to only a few areas along the coast and yielded rough estimates of long-term changes. In a more detailed study but limited to Lincoln County, Smith (1978) also used aerial photographs to document average cliff-erosion rates. Both studies revealed a considerable degree of variability along even short distances of the coast. They also recognized the episodic nature of the cliff erosion processes.

Our ongoing Sea Grant research is focusing on the patterns and processes of cliff erosion along the Oregon coast. This work has examined the tectonic controls on the spatial variability of cliff erosion along the full length of the coast, beach-process factors in cliff retreat within more limited stretches of shore, erosion/management issues at specific locations, and the impacts of engineering structures (Komar and McDougal, 1988; Sayre and Komar, 1988; Komar and others, 1991; Komar and Shih, 1991).

Our research has confirmed that sea-cliff erosion is highly variable along the Oregon coast but suggests that the patterns are systematic and depend in part on the tectonic uplift versus global sea-level rise (Figure 3). The north-central portion of the coast, including the areas of Newport and Lincoln City, is experiencing some relative sea-level rise, while further north toward Cannon Beach and south of Coos Bay, the tectonic uplift has exceeded the rate of sea-level rise, at least within historic times. There is a rough first-order parallelism between the extent of cliff erosion and relative sea-level changes, with greater amounts of erosion occurring in the Lincoln City area of the central coast (Komar and Shih, 1991).

Of particular interest is the minimal erosion within historic times of sea cliffs in the Cannon Beach and Bandon areas. What little cliff retreat exists is associated with ground-water seepage, whereas direct wave attack of cliffs backing the beach accounts for little or no erosion. Yet the steepness of the cliff and its alongshore uniformity without appreciable degradation by subaerial processes suggest that the cliff has experienced wave erosion in the not-too-distant past. This condition is more evident at Bandon on the south coast, where, in addition to the steep cliff backing the beach, a number of stacks exist in the immediate offshore, many having flat tops that continue the level of the marine terrace (Komar and others, 1991). Our interpretation of both the Cannon Beach and Bandon areas is that cliff erosion was initiated following the last major subduction earthquake 300 years ago, an event that likely resulted in the abrupt subsidence of those areas. However, the subsequent aseismic uplift has progressively diminished the cliff erosion to the point where it has essentially ceased at Cannon Beach and Bandon. The central coast around Lincoln City likely also experienced subsidence followed by uplift, but its rates of uplift have been insufficient, relative to rising sea level, to halt continued cliff erosion.

Such tectonic/sea-level controls of cliff erosion along the Oregon coast can be viewed as a first-order pattern or trend. Superimposed on this coastwide variability are more local processes that can be viewed as second-order factors. Most important is the size of the beach, since it governs the ability of the beach to act as a buffer between the sea cliffs and the eroding processes of waves and nearshore currents. That size varies from one littoral cell to another, the stretches of beach isolated by rocky headlands. For example, the beach extending north from Yaquina Head to Otter Rock and Cape Foulweather, the Beverly Beach littoral cell, does not offer adequate buffer protection, and as a result the sea cliffs backing this beach have undergone significant retreat (though still at low rates when compared with other coastlines). Its limited buffering capacity is evident in our ongoing measurements of wave run-up (Shih, unpublished data). The objective is to document the frequency with which waves reach the talus and base of the sea cliff and the intensity of the swash run-up when it does so; video-analysis techniques are being employed to record the run-up. Measurements have established that the swash of waves frequently reaches the cliff base in the Beverly Beach cell but rarely in the other cells. Beach surveys show that this is due to the low elevations of the beach profile with respect to mean sea level and high-tide elevations.

Of particular interest in our study of sea-cliff erosion has been the littoral cell containing Lincoln City and Gleneden Beach, extending north from Government Point (Depoe Bay) to Cascade Head. This cell is of interest due in part to the extensive development along this stretch of coast and the associated management problems. In addition, one unusual feature enhances its scientific interest: there are marked longshore variations in the coarseness of beach sands, and this produces longshore changes in beach morphology, in the nearshore processes, and in the resulting factors important to cliff erosion. We have completed a detailed study of the changing grain-size distributions from beach-sand samples collected along the full length of this cell (Shih, unpublished data). Our analyses show that the longshore variations in grain sizes are produced by the relative proportions of discrete grain-size modes within the overall sand-size distributions. We have succeeded in tracing these individual modes back to specific areas of the eroding sea cliffs. Of interest are (1) the longshore movements and mixing of these grain-size modes, and (2) questions as to why the mixing processes of the nearshore have not succeeded in homogenizing the beach sands to eliminate longshore variations. However, the overall effect of this longshore sorting is that the beaches toward the central to south part of the cell are coarsest; this includes the beaches fronting Siletz Spit and the community of Gleneden Beach. Sand sizes decrease somewhat toward the south but particularly toward the north, where the sand is finest in the Roads End area of Lincoln City. The effects on the beach morphology are significant, with the coarse-grained beach at Gleneden being a steep "reflective" beach for most of the year while the beach at Roads End has a low slope and is highly "dissipative" of the waves as they cross the wide surf zone.

Beach profiles have been obtained from eleven stations spaced at roughly even intervals along the length of the Lincoln City littoral cell in order to document the beach morphologies and how they change with sediment sizes. Furthermore, high-density profiling has been undertaken at approximately monthly intervals for over a year at Gleneden Beach State Park (reflective beach) and at the 21st Street beach access at the northern end of Lincoln City (dissipative beach). This high-density profiling permits generation of detailed topographic maps of the beach and more accurate analyses of seasonal changes. Of particular interest in this series of profiles is the contrast in the response of the reflective and dissipative beaches to winter storms and the determination of whether they offer different degrees of buffering protection for the sea cliffs. The results document that the profile changes and the accompanying quantities of cross-shore sediment transport are much greater on the coarse-grained reflective beach (Gleneden Beach) than on the finer grained dissipative beach at the north end of the littoral cell. The rates of change as well as total quantities of sand moved under a given storm are larger on the steep reflective beach. This makes the reflective beach a weaker buffer from wave attack, and cliff erosion is therefore more active than in the area where the cliff is fronted by a fine-grained dissipative beach. In addition, we have found that the development of rip-current embayments is extremely important on the reflective beach and largely controls the locations of maximum episodic cliff erosion. The process is similar to that described earlier for the erosion of Siletz Spit, immediately north of Gleneden Beach, which is also fronted by a reflective beach (Figure 18). Ground observations and aerial photographs show that rip currents on steep reflective beaches tend to cut narrow, deep embayments, so they play a significant role in controlling the erosion impact along the sand spit and also in the the sea-cliff areas. In contrast, rip-current embayments on the dissipative beaches of north Lincoln City and elsewhere on the coast are broader in their longshore extents, but they do not cut as deeply through the beach berm.

Bluff retreat in north Lincoln City, behind the dissipative beach, depends mainly on subaerial processes of rainfall against the cliff face and ground-water seepage. People have also had a significant impact; in some places their carving graffiti on the cliff face is the dominant factor in bluff retreat (Figure 30). The loosened material accumulates as talus at the base of the cliff. That accumulation can continue for several years, until it is removed by wave action

Figure 30. Retreat of bluff in Lincoln City caused by children carving graffiti and digging caves.

during an unusually severe storm accompanied by high-tide levels. There is little direct wave attack on the cliff and no evidence of undercutting. However, once the talus has been removed by waves, sloughing of the cliff surface accelerates so that a new mass of talus quickly forms.

Landsliding has been a problem at some locations along the Oregon coast. This is particularly the case where Tertiary marine formations are included in the sea cliff (cover photo, lower left), since their muddy consistency makes them particularly susceptible to sliding. Furthermore, it has been estimated that these units dip seaward along more than half of the northern Oregon coast (Byrne, 1964; North and Byrne, 1965), a geometry which also contributes to their instability. In some cases this instability results in the slow mass movement of the cliff material toward the sea, amounting to only a few tens of centimeters per year. Although the movement is slow, it thoroughly disrupts the land mass and any attempts to place developments on the site. Other landsliding involves the wholescale movement of large masses at more rapid rates. Best known is the infamous Jump-Off Joe area of Newport. In 1942, a large landslide developed in the bluff, carrying more than a dozen homes to their destruction (Sayre and Komar, 1988). In spite of the area's continued slumping, in 1982 a condominium was built on a small remnant of bluff adjacent to the major slide. Within three years, slope retreat had caused the foundation to fail (Figure 31), and the unfinished structure had to be destroyed by the city.

SUMMARY

The Oregon coast is renowned for the intensity of its wave conditions. The winter storms commonly generate individual waves having heights of 40-50 ft, with a 95-ft record height. Such storm waves deliver a tremendous amount of energy to our coast, cutting back beaches and attacking coastal properties. They are assisted by rip currents that locally erode embayments into the beach, as well as tides and other processes that elevate water levels in the nearshore. In addition to these natural processes, people have contributed to the erosion, ranging from a child carving his name on the face of a sea cliff to

Figure 31. Construction (above) and destruction (below) of condominium built in 1982 and small remnant of marine terrace at Jump-Off Joe. From Sayre and Komar (1988).

the Corps of Engineers constructing a jetty at the inlet to Tillamook Bay.

The Oregon coast has had its share of erosion problems. Most dramatic has been the impact on sand spits; several case studies have been summarized in this paper. Though less dramatic, the cumulative erosion of sea cliffs has affected a number of coastal communities as well as parklands and highways. However, the Oregon coast has actually suffered relatively few erosion impacts leading to major property losses, at least in comparison with most other coastal states. This is in part due to its physical setting. The coast consists of a series of pocket beaches or littoral cells separated by rocky headlands or more extensive stretches of rocky shore. In each cell there is a seasonal reversal in the direction of longshore sand transport, but with a long-term net drift that is essentially zero. As a result, the construction of jetties on the Oregon coast has caused only a local rearrangement of beach sands and adjustments of the shorelines with no lasting major impacts. (The one exception was Bayocean Spit, due to the construction of one jetty rather than two.) This contrasts with most U.S. shorelines, where jetty and breakwater construction has blocked a net littoral drift and severely eroded the downdrift beaches and communities.

The tectonic setting of the Oregon coast is also important in limiting its erosion. Most important is the tectonic uplift that presently exceeds the global rise in sea level over much of the coast, while it minimizes the transgression of the sea in other areas. Unlike the east and Gulf coasts of the U.S., where the transgression has resulted in substantial landward migrations of the shoreline and property losses, erosion of Oregon's sandy shores is cyclical with minimal net loss. This was first noted on Siletz Spit, where an episode of erosion cutting into the foredunes was followed by a decade of accretion so that the dunes built back out to their former extent. An extreme example was noted on Nestucca Spit, where an extensive mound of riprap placed during erosion in 1978 is now covered by dune sands that are blowing inland, inundating houses. Similarly, the tectonic uplift has resulted in low rates of cliff recession, much smaller than documented in other coastal areas.

This may change in the future. There is the potential for accelerated rates of sea-level rise due to greenhouse warming that could exceed the tectonic rise and bring about more extensive erosion. Although the impact would be smaller and come later than along the low-relief and subsiding coastal states, it is important that potential increases in sea level enter into management considerations for the Oregon coast. More ominous is the possibility that an extreme earthquake will occur on the Northwest coast. In addition to the immediate impacts of the ground shaking and the generation of a tsunami, the abrupt subsidence of portions of the coast will initiate extensive erosion in areas that have not suffered from wave attack within historic times. The implications of this scenario for coastal planning are staggering, yet the decisions are not simple ones. As discussed above, it has been estimated that catastrophic earthquakes and land-level changes have occurred at least six times in the past 4,000 years, at intervals ranging from 300 to 1,000 years. The last recorded event took place about 300 years ago, so we are clearly in the window of potential for another event. At some stage, and preferably sooner than later, coastal management decisions need to be made that reflect this potentially extreme hazard. In the mean time, we have to reflect on the wisdom of developing low-lying areas and the edges of ocean cliffs along the coast.

In developing the Oregon coast, we have made numerous mistakes that have placed homes and condominiums in the path of erosion. Development has been permitted in foredunes of sand spits immediately backing the beach, along the edges of precipitous sea cliffs, and even in the area of the active Jump-Off Joe landslide. Such unwise developments and the accompanying proliferation of seawalls and riprap revetments have progressively degraded the qualities of the Oregon coast that we cherish.

ACKNOWLEDGMENTS

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MINERAL EXPLORATION ACTIVITY

MAJOR MINERAL EXPLORATION ACTIVITY

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Cracker Creek Mine Bourne Mining Corp.	T. 8 S. R. 37 E.	Gold	Expl
Baker 1991	Aurora Ridge Western Cons. Mines	T. 10 S. Rs. 35.5, 36	Prec. Metals	Expl
Baker 1991	Cave Creek Nerco Exploration	Tps. 11, 12 S. R. 42 E.	Gold	App
Baker 1991	Gold Hill Golconda Resources	T. 12 S. R. 43 E.	Gold	App
Baker 1991	Gold Powder Kennecott Expl. Co.	Tps. 9, 10 S. Rs. 41, 42 E.	Gold	Expl
Baker 1991	Gold Ridge Mine Golconda Resources	T. 12 S. R. 43 E.	Gold	Expl
Baker 1991	Lower Granview Earth Search Sciences	T. 14 S. R. 37 E.	Gold	App
Baker 1992	Pole Creek Placer Dome U.S.	T. 13 S. R. 36 E.	Gold, silver	Expl
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	Gold	Expl com
Crook 1988	Bear Creek Independence Mining	Tps. 18, 19 S. R. 18 E.	Gold	Expl
Grant 1991	Buffalo Mine American Amex	T. 8 S. R. 35½ E.	Gold	App
Grant 1991	Canyon Mtn. Cammtex International	T. 13 S. R. 32 E.	Gold	Expl
Grant 1992	Standard Mine Bear Paw Mining	T. 12 S. R. 33 E.	Gold, copper	Expl
Harney 1990	Pine Creek Battle Mtn. Exploratn.	T. 20 S. R. 34 E.	Gold	Expl
Harney 1991	Buck Mtn.-North Teck Resources, Inc.	T. 24 S. R. 36 E.	Gold	App
Harney 1991	Flagstaff Butte Noranda Exploration	Tps. 3, 9 S. R. 37 E.	Gold	App
Harney 1991*	Adobe Flat Phelps Dodge	T. 28 S. R. 34 E.	Gold	App
Jackson 1991*	Al Sarena Project Fischer-Watt Gold Co.	T. 31 S. R. 2 E.	Gold	App
Jefferson 1991	Red Jacket Bond Gold	Tps. 9, 10 S. R. 17 E.	Gold	App
Lake 1988	Quartz Mountain Wavecrest Resources.	T. 37 S. R. 16 E.	Gold	Expl
Lake 1990	Glass Butte Galactic Services	Tps. 23, 24 S. R. 23 E.	Gold	Expl
Lake 1991	8th Drilling Series Wavecrest Resources	T. 37 S. R. 17 E.	Gold	Expl
Lincoln 1991	Iron Mtn. Quarry Oreg. St. Highw. Div.	T. 10 S. R. 11 W.	Basalt	App
Linn 1991	Hogg Rock Oreg. St. Highw. Div.	T. 13 S. R. 7½ E.	Rock	App
Linn 1991	Quartzville Placer Dome U.S.	T. 11 S. R. 4 E.	Gold, silver	App
Malheur 1988	Grassy Mountain Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl, com
Malheur 1988	Harper Basin Project Amer. Copper & Nickel	T. 21 S. R. 42 E.	Gold	Expl
Malheur 1988	Jessie Page Chevron Resources	T. 25 S. R. 43 E.	Gold	Expl
Malheur 1988	Kerby Malheur Mining	T. 15 S. R. 45 E.	Gold	Expl, com
Malheur 1989	Hope Butte Chevron Resources	T. 17 S. R. 43 E.	Gold	Expl, com
Malheur 1990	Ali/Alk Atlas Precious Metals	T. 17 S. R. 45 E.	Gold	Expl

MAJOR MINERAL EXPLORATION ACTIVITY (continued)

County, date	Project name, company	Project location	Metal	Status
Malheur 1990	Calavera NERCO Exploration	T. 21 S. R. 45 E.	Gold	Expl
Malheur 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E.	Gold	Expl
Malheur 1990	Freezeout Western Mining Corp.	T. 23 S. R. 42 E.	Gold	Expl
Malheur 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E.	Gold	Expl
Malheur 1990	Grassy Mtn. Regional Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl
Malheur 1990	KRB Placer Dome U.S.	T. 25 S. R. 43 E.	Gold	App
Malheur 1990	Mahogany Project Chevron Resources	T. 26 S. R. 46 E.	Gold	App
Malheur 1990	Racey Project Ican Minerals, Ltd.	T. 13 S. R. 41 E.	Gold	Expl
Malheur 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E.	Gold	Expl
Malheur 1990	Stockade Mountain BHP-Utah Internatl.	T. 26 S. Rs. 38, 39 E.	Gold	Expl
Malheur 1990	Stockade Project Phelps Dodge Mining	Tps. 25, 26 S. R. 38 E.	Gold	Expl
Malheur 1991	Bannock Atlas Precious Metals	T. 25 S. R. 45 E.	Gold	App
Malheur 1991	Big Red Ron Johnson	T. 20 S. R. 44 E.	Gold	Expl
Malheur 1991	Birch Creek Ronald Willden	T. 15 S. R. 44 E.	Gold	App
Malheur 1991	Buck Mtn.-South Teck Resources, Inc.	T. 24 S R. 37 E.	Gold	App
Malheur 1991	Deer Butte Atlas Precious Metals	T. 21 S. R. 45 E.	Gold	App
Malheur 1991	Harper Basin Atlas Precious Metals	T. 21 S. R. 42 E.	Gold	App
Malheur 1991	Quartz Mtn. Basin BHP-Utah Intl., Inc.	T. 24 S. R. 43 E.	Gold	App
Malheur 1991	Rhinehardt Site Atlas Precious Metals	Tps. 18, 19 S. R. 45 E.	Gold	Expl
Malheur 1991	Sagebrush Gulch Kennecott Exploration	Tps. 21, 22 S. R. 44	Gold	App
Malheur 1991	White Mountain D.E. White Mtn. Mining	T. 18 S. R. 41 E.	Dia-toms	App
Marion 1990	Bornite Project Plexus Resources	T. 8 S. R. 3 E.	Copper	App com

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

Regulatory Issues

Final rules implementing the major legislation affecting the permit procedure for heap-leach mining have been adopted by the Department of Geology and Mineral Industries. Hearings have been held for the related rules that are being written by the Department of Environmental Quality (DEQ), the Water Resources Department (WRD), and the Oregon Department of Fish and Wildlife (ODFW). Adoption of the rules by DEQ, WRD, and ODFW was scheduled for their respective commissions in December.

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

Significant Oregon earthquakes in 1991

The months of October, November, and December all saw Oregonians feeling the earth shake restlessly beneath them. In October, some residents in the Portland area felt the largest two tremors of a swarm numbering over ten. The swarm occurred during the period October 17-21, 1991. The felt earthquakes occurred on October 17 and October 20 and were assigned magnitudes of 3.1 and 3.0, respectively. The epicenters were in the same area as the July 22 swarm of earthquakes previously reported in *Oregon Geology* (September issue, p. 127). While this concentration of activity is very intriguing, nothing conclusive can be said about its significance. An interesting sidelight to the latest swarm is the fact that it began on the anniversary of the 1989 Loma Prieta ("World Series") earthquake and during the airing of a DOGAMI-assisted television show on local earthquake hazards. As it was, the timing and strength were not good enough to shake the camera during a live shot.

On November 27, 1991, at 5:09 p.m., a magnitude-4 earthquake (3.9 Wood-Anderson, 4.2 average coda) occurred at lat 45°59.43′N., long 118°18.29′W., which is northeast of Milton-Freewater in Umatilla County. At least 15 aftershocks were recorded from this event, the largest being magnitude 2. The earthquake was felt in Milton-Freewater and, in the State of Washington, in Walla Walla, Waitsburg, and Dayton. No damage was reported.

On December 15, 1991, at 2:14 p.m., another earthquake occurred near Milton-Freewater. This earthquake registered a magnitude of 3.3 (coda magnitude). It was located at lat 46°01.16′N., long 118°19.63′W., which is northwest of where the November event was located and just across the border into Washington. The December 15th earthquake was accompanied by two foreshocks and four aftershocks, all less than magnitude 2. □

New geologic map of Portland quadrangle released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a new geologic map of the Portland 7½-minute quadrangle, which includes the central and northern portions of the Portland metropolitan area. The map is part of a mapping project intended to serve as an important basic tool for earthquake-hazard mitigation.

Geologic map of the Portland quadrangle, Multnomah and Washington Counties, Oregon, and Clark County, Washington, by M.H. Beeson, T.L. Tolan, and I.P. Madin. DOGAMI Geological Map Series GMS-75, full-color map, scale 1:24,000. Price $7.

The new map is printed on a sheet approximately 27 by 40 inches in size. The geology of the quadrangle is shown with about 20 differentiated bedrock and surficial rock units and their structural relationships, both on the map and on two accompanying cross sections. The structure of the Portland Hills area in the quadrangle is discussed briefly in a special text section.

This map was produced and published as part of an earthquake-hazard study in the Portland metropolitan area and funded in part by the U.S. Geological Survey and the National Earthquake Hazard Reduction Program. It represents the second full-color geologic quadrangle map of the project. A map of the Lake Oswego quadrangle, which lies adjacent to the south, was released in 1989 as GMS-59. Both maps are now available at the Oregon Department of Geology and Mineral Industries, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. The price is $7. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders. □

Haggerty-Foster joins DOGAMI Governing Board

Jacqueline G. Haggerty-Foster of Pendleton has been appointed by Governor Barbara Roberts and confirmed by the Oregon Senate for a four-year term as member of the Governing Board of the Oregon Department of Geology and Mineral Industries (DOGAMI).

Haggerty-Foster takes the place of Sidney R. Johnson of Baker City, whose term expired. She is currently legal counsel to Umatilla County. From 1985 to 1987, she was an assistant legal counsel and land-use hearing officer for Marion County. Prior to that, she served as a hearings officer with the Oregon Department of Revenue. She holds degrees from Washington State University (B.A.) and the Willamette University School of Law (J.D.).

Serving with Haggerty-Foster on the three-member board are Ronald K. Culbertson of Myrtle Creek, president of the South Umpqua State Bank in Roseburg and current chair, and John W. Stephens of the Portland law firm Esler, Stephens, and Buckley. □

OAS to hold 50th meeting

The bench mark fiftieth annual meeting of the Oregon Academy of Science (OAS) is scheduled for Saturday, February 22, 1992, at Willamette University in Salem, Oregon.

The meeting is also considered a "warmup" for the annual meeting of the Geological Society of America, Cordilleran Section, to be held this year in Eugene on May 11-13.

Program plans for the OAS meeting include a new session on environment-related topics in addition to traditional geologic presentations. A preliminary program is to be released during February.

Contact person for further information on program details, papers, or abstracts is Michael Cummings, Department of Geology, Portland State University, Box 751, Portland, OR 97207, phone (503) 725-3022. *—OAS release*

Placer task force releases final report, declares duties completed

The Oregon Placer Minerals Technical Task Force has announced the release of its final technical report detailing the results of mineral-resource and environmental investigations conducted during 1990-91. The task force met in Newport, Oregon, on October 10, 1991, to consider the new information and make recommendations to the Secretary of the Interior and the Governor of Oregon.

Don Hull, State Geologist and a task force cochair, said the group had fulfilled its duties and should be disbanded. "The study failed to show any rich or unique mineral resources offshore southern Oregon that would justify further resource effort at this time, but we are recommending that the biological studies be continued under other existing programs," he said.

After making a preliminary examination of existing data, the group had commissioned a geological and biological reconnaissance of areas offshore Cape Blanco and the mouth of the Rogue River. A research cruise was conducted in September and October, 1990, and the resulting samples and data were analyzed during much of 1991.

The mineral reconnaissance found all mineral concentrations to be subeconomic—except for those of titanium in samples taken off Cape Blanco. Still, according to task force cochair Lisle Reed of the Minerals Management Service, "Three percent titanium is only equivalent to that in marginally attractive land-based resources."

The biological sampling demonstrated a diversity of habitat and the presence of fish and invertebrate communities that are similar to those found in other sand-bottomed areas on the Oregon continental shelf.

The task force was established in September 1988 to study the economic and environmental aspects of the possible development of offshore "black sand" deposits off southern Oregon. Federal agencies with membership in the task force were the Minerals Management Service, the U.S. Geological Survey, the U.S. Bureau of Mines, and the U.S. Fish and Wildlife Service. State membership was through the Department of Geology and Mineral Industries, the Department of Land Conservation and Development, the Department of Fish and Wildlife, the Division of State Lands, and the Oregon Coastal Zone Management Association. Advisors to the task force represented Oregon State University, the Environmental Protection Agency, the Oregon Environmental Council, the National Oceanic and Atmospheric Administration, the U.S. Army Corps of Engineers, Goldfields Mining Corporation, and the University of Mississippi Marine Minerals Technology Center.

The task force's final report is entitled ***Preliminary Resource and Environmental Data: Oregon Marine Placer Minerals.*** The 231-page document includes sections on geology/geophysics, mineralogy/geochemistry, mineral processing, environmental geochemistry, and biology and a section with conclusions. It is published as Oregon Department of Geology and Mineral Industries Open-File Report O-91-2 and is now available at the Department, 910 State Office Building, 1400 SW Fifth Avenue, Portland, Oregon 97201-5528. The price is $10. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 229-5639. Orders under $50 require prepayment except for credit-card orders.☐

USGS offers new publications

The U.S. Geological Survey (USGS) has released the first volumes of a new publication series, the **Digital Data Series (DDS).** The data are made available on CD-ROM and intended for use on DOS-based computer systems. Price will generally be $32. Currently available are the following:

- DDS-1: National geochemical data base: NURE data for the conterminous western United States.
- DDS-2: Digital geologic coverage of Nevada.
- DDS-4: 1:2,000,000-scale line graph data.
- DDS-5: Aerial photography summary record system (APSRS).

In a more traditional publishing manner, the USGS has released a new special map of the **National Wild and Scenic River System** (identification number US-5664). Printed on both sides, the 28x42-inch map sheet shows major streams in blue and their wild and scenic river segments in red—for the 48 contiguous states on one side and for Alaska on the other.

Additional color photographs show rafters on the Selway River in Idaho, and scenes of the Allagash River in Maine, Charley River in Alaska, Delaware River in New Jersey and Pennsylvania, Merced River in California, Missouri River in Montana, St. Croix River in Wisconsin, and Salmon River in Oregon.

The 123 rivers in 33 states that are shown included in the wild and scenic river system represent the status as December 1990. Oregon with 42 and Alaska with 25 have more than half the rivers in the system. Only 23 of the rivers are east of the Rocky Mountains.

The map sells for $4.50. On mail orders for less than $10, an additional $1 must be added for postage and handling.

The USGS sells these publications at its Map Distribution Center, Box 25286, Federal Center, Denver, CO 80225, and over the counter at USGS Earth Science Information Centers in cities such as Anchorage, Alaska; Menlo Park and San Francisco, California; Spokane, Washington; and—coming soon—Portland, Oregon. ☐

AIPG invites to meeting in Nevada

The American Institute of Professional Geologists (AIPG) is sponsoring a symposium, open to all geologists, on "Geologic Reason, a Basis for Decisions Affecting Society." It is to be held in conjunction with the AIPG 1992 annual meeting on September 27-30, 1992, at Caesar's Tahoe Hotel and Convention Center in Lake Tahoe, Nevada.

For the technical sessions, posters are invited on the following subjects: (1) modeling geologic phenomena, (2) the role of the geologist in predicting earthquakes, (3) the role of the geologist in cleaning up wastes, (4) environmental hazards—from asbestos to radon, and (5) management of federal lands.

Further information is available from Jon Price, Nevada Bureau of Mines and Geology, M.S. 178, University of Nevada, Reno, NV 89557-0088, phone (702) 784-6691, FAX (702) 784-1709.

—AIPG release

GHC offers second edition of guidebook

The Geo-Heat Center (GHC) of the Oregon Institute of Technology announces the release of the second edition of its direct-use guidebook:

Geothermal Direct Use Engineering and Design Guidebook, 445 p., $25 hard cover, $20 soft cover. Foreign orders add $3 for surface mail or $15 for air mail. Available from Geo-Heat Center, Oregon Institute of Technology, 3201 Campus Drive, Klamath Falls, OR 97601, phone (503) 885-1750.

The revised and updated Guidebook was prepared for the U.S. Department of Energy. It is the product of a cooperative effort by the Oregon Institute of Technology, the Idaho National Engineering Laboratory, the University of Utah Research Institute, Battelle Pacific Northwest Laboratories, Radian Corporation, and the Washington State Energy Office.

Engineers and developers will find the Guidebook an important source of technical information on low- and moderate-temperature (100° to 300 °F) geothermal applications and equipment. Chapters cover exploration, well drilling, space heating and cooling, greenhouse heating, aquaculture, industrial processes, economics, regulations, and environmental aspects.

—GHC release

Laterite and bauxite analyses for gold and 29 other elements now open to public

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released analytical data on Department samples that were analyzed by a private exploration company. The data are now available to the public after expiration of the statutory period of confidentiality.

A report consisting of five pages of analytical data and a one-page summary of analytical procedures was compiled by G.L. Baxter and contains analyses for 30 elements, including gold, of 181 laterite and bauxite samples.

Most of the samples (145) had been collected by Department staff during the mid-1970s for a study of nickel in Oregon (DOGAMI Miscellaneous Paper 20) and were re-analyzed now. The other 36 laterite and bauxite samples had been collected in the 1940s and 1950s. A separate list provides locality information for some samples that had not been included in the nickel study. The data are of major interest for gold exploration.

To obtain a copy of the data, contact Gary L. Baxter at the DOGAMI Portland office (see address on page 2 of this issue).☐

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

GEOLOGICAL MAP SERIES

		Price	√
GMS-4	Oregon gravity maps, onshore and offshore. 1967	4.00	
GMS-5	Powers 15-minute quadrangle, Coos and Curry Counties. 1971	4.00	
GMS-6	Part of Snake River canyon. 1974	8.00	
GMS-8	Complete Bouguer gravity anomaly map, central Cascade Mountain Range. 1978	4.00	
GMS-9	Total-field aeromagnetic anomaly map, central Cascade Mountain Range. 1978	4.00	
GMS-10	Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	4.00	
GMS-12	Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	4.00	
GMS-13	Huntington and parts of Olds Ferry 15-minute quadrangles, Baker and Malheur Counties. 1979	4.00	
GMS-14	Index to published geologic mapping in Oregon, 1898-1979. 1981	8.00	
GMS-15	Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	4.00	
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GMS-37	Mineral resources, offshore Oregon. 1985	7.00	
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GMS-41	Elkhorn Peak 7½-minute quadrangle, Baker County. 1987	7.00	
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33	Bibliography of geology and mineral resources of Oregon (1st supplement, 1936-45). 1947	4.00	
35	Geology of the Dallas and Valsetz 15-minute quadrangles, Polk County (map only). Revised 1964	4.00	
36	Papers on Foraminifera from the Tertiary (v. 2 [parts VII-VIII] only). 1949	4.00	
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46	Ferruginous bauxite, Salem Hills, Marion County. 1956	4.00	
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61	Gold and silver in Oregon. 1968 (reprint)	20.00	
65	Proceedings of the Andesite Conference. 1969	11.00	
67	Bibliography of geology and mineral resources of Oregon (4th supplement, 1956-60). 1970	4.00	
71	Geology of lava tubes, Bend area, Deschutes County. 1971	6.00	
78	Bibliography of geology and mineral resources of Oregon (5th supplement, 1961-70). 1973	4.00	
81	Environmental geology of Lincoln County. 1973	10.00	
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100	Geology and mineral resources of Josephine County. 1979	10.00	
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16 Index to the *Ore Bin* (1939-1978) and *Oregon Geology* (1979-1982). 1983	5.00	
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00	
18 Investigations of talc in Oregon. 1988	8.00	
19 Limestone deposits in Oregon. 1989	9.00	
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21 Field geology of the NW¼ Broken Top 15-minute quadrangle, Deschutes County. 1987	6.00	
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23 Forum on the Geology of Industrial Minerals, 25th, 1989, Proceedings. 1990	10.00	
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3 Preliminary identifications of Foraminifera, General Petroleum Long Bell #1 well. 1973	4.00	
4 Preliminary identifications of Foraminifera, E.M. Warren Coos County 1-7 well. 1973	4.00	
5 Prospects for natural gas, upper Nehalem River Basin. 1976	6.00	
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Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00	
Geothermal resources of Oregon (published by NOAA). 1982	4.00	
Index map of available topographic maps for Oregon published by the U.S. Geological Survey	Free	
Bend 30-minute quadrangle geologic map and central Oregon High Cascades reconnaissance geologic map. 1957	4.00	
Lebanon 15-minute quad., Reconnaissance geologic map. 1956	4.00	
Mist Gas Field Map, showing well locations, revised 1991 (Open-File Report O-91-1, ozalid print, incl. production data)	8.00	
Northwest Oregon, Correlation Section 24. Bruer and others, 1984 (published by AAPG)	6.00	
Oregon rocks and minerals, a description. 1988 (DOGAMI Open-File Report O-88-6; rev. ed. of Miscellaneous Paper 1)	6.00	
State laws governing quartz and placer claims	Free	
Back issues of *Ore Bin/Oregon Geology*, 1939-April 1988	1.00	
Back issues of *Oregon Geology*, May/June 1988 and later	2.00	
Color postcard: Oregon State Rock and State Gemstone	1.00	

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request. The Department also sells Oregon topographic maps published by the U.S. Geological Survey.

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Check desired publications in list above and enter total amount below. Send order to address above or FAX (503) 229-5639. Minimum mail order $1.00. Payment must accompany orders of less than $50. Payment in U.S. dollars only. Publications are sent postpaid. All sales are final. Subscription price for *Oregon Geology*: $8 for 1 year, $19 for 3 years.

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VOLUME 54, NUMBER 2 MARCH 1992

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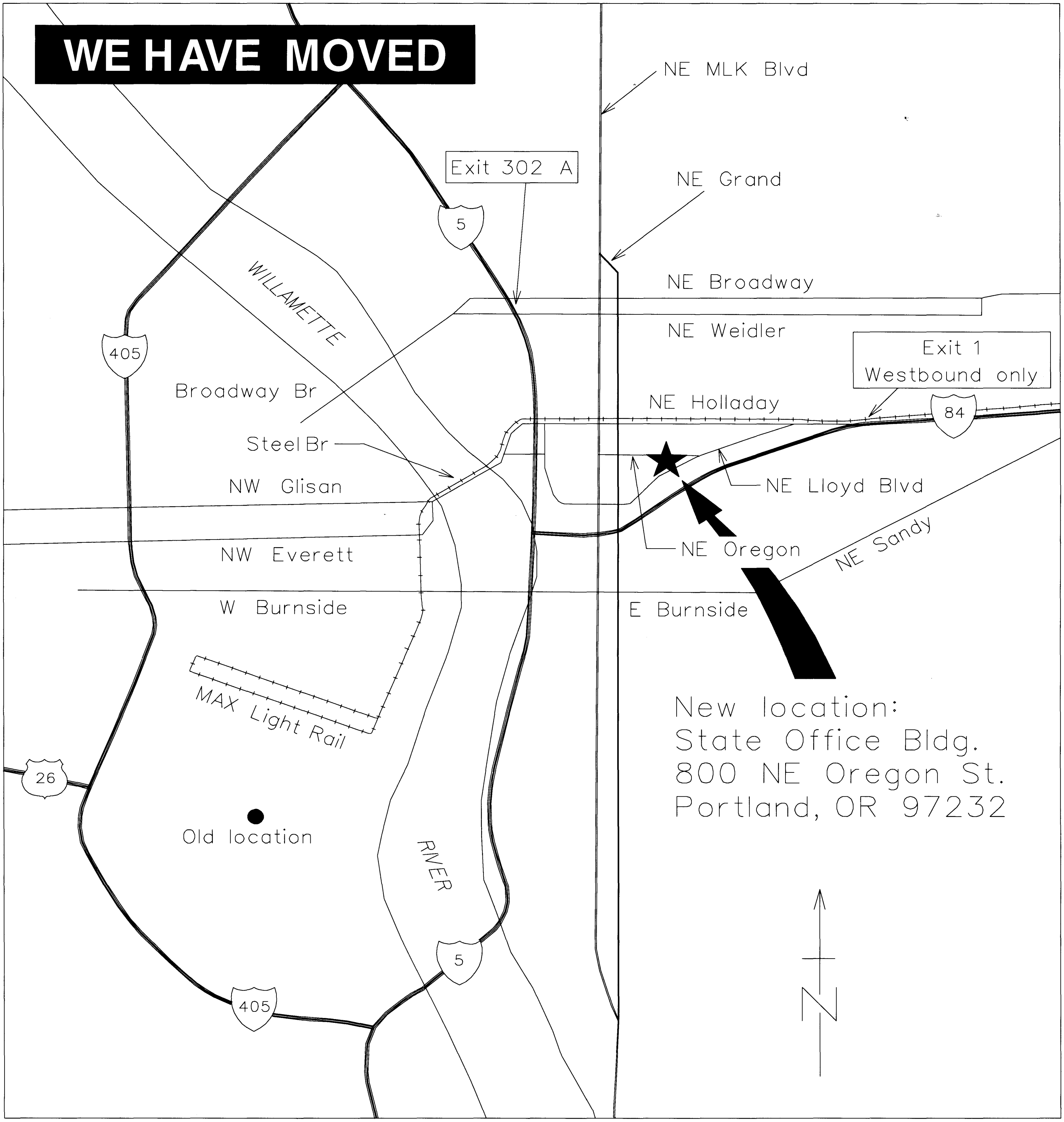

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Main Office: Suite 965, 800 NE Oregon Street # 28, Portland 97232, phone (503) 731-4100, FAX (503) 731-4066.

Baker City Field Office: 1831 First Street, Baker City 97814, phone (503) 523-3133.

Grants Pass Field Office: 5375 Monument Drive, Grants Pass 97526, phone (503) 476-2496. Thomas J. Wiley, Resident Geologist.

Mined Land Reclamation Program: 1534 Queen Ave. SE, Albany 97321, phone (503) 967-2039. Gary W. Lynch, Supervisor.

Second class postage paid at Portland, Oregon. Subscription rates: 1 year, $8; 3 years, $19. Single issues, $2. Available back issues of *Ore Bin/Oregon Geology* through v. 50, no. 4, $1. Address subscription orders, renewals, and changes of address to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232. Permission is granted to reprint information contained herein. Credit given to the Oregon Department of Geology and Mineral Industries for compiling this information will be appreciated. POSTMASTER: Send address changes to *Oregon Geology*, Suite 965, 800 NE Oregon Street # 28, Portland 97232.

Information for contributors

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

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

"Lost our lease"—?

Well, no, the Department of Geology and Mineral Industries is still in the State Office Building. But it's the **new** State Office Building, located east of downtown Portland and the Willamette River, just south of the Lloyd Center shopping mall. The map on the cover shows the main approaches and the geographic relation between the old and the new State Office Buildings. See the box above for our new mailing address and phone and FAX numbers. And even before you get to the offices on the 9th floor, you will find, on the ground floor, our new **Nature of Oregon Information Center** (Suite 177), where our maps and other publications will be sold.

MINERAL EXPLORATION ACTIVITY

Regulatory Issues

Final rules implementing the major legislation affecting the permit procedure for heap-leach mining have been adopted by the Department of Geology and Mineral Industries, the Water Resources Department, and the Department of Fish and Wildlife. The Department of Environmental Quality rules for heap-leach-pad liner design, detoxification standards, etc., are undergoing further review prior to being resubmitted to the Environmental Quality Commission for adoption.

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

Major mineral exploration activity

No new project applications were received. Because of space limitations in this issue, the table below lists only those projects from the table published in the last (January 1992) issue of *Oregon Geology* that were affected by changes or corrections.

County, date	Project name, company	Project location	Metal	Status
		Permits closed		
Baker 1991	Lower Granview Earth Search Sciences	T. 14 S. R. 37 E.	Gold	App
Harney 1991	Buck Mtn.-North Teck Resources, Inc.	T. 24 S. R. 36 E.	Gold	App
Harney 1991	Adobe Flat Phelps Dodge	T. 28 S. R. 34 E.	Gold	App
Jefferson 1991	Red Jacket Bond Gold	Tps. 9, 10 S. R. 17 E.	Gold	App
Malheur 1990	Calavera NERCO Exploration	T. 21 S. R. 45 E.	Gold	Expl
Malheur 1991	Buck Mtn.-South Teck Resources, Inc.	T. 24 S R. 37 E.	Gold	App
		Changes or corrections in bold print		
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	**Chromite, zircon**	Expl com
Malheur 1988	Jessie Page **M.K. Gold Co.**	T. 25 S. R. 43 E.	Gold	Expl
Malheur 1990	Mahogany Project **Cyprus Minerals**	T. 26 S. R. 46 E.	Gold	App
Malheur 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E.	Gold	**Veg**

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

OIL AND GAS NEWS

NWPA schedules symposium and meetings

The Northwest Petroleum Association (NWPA) has scheduled the 1992 annual symposium for October 11-14 in Lincoln City, Oregon. The theme for the symposium is Pacific Northwest Petroleum Development: Geology, geophysics, land, and legal. The symposium chairman is Bob Deacon, consulting geologist. Information can be obtained from the NWPA, P.O. Box 6679, Portland, OR 97228-6679.

The NWPA will hold its next monthly meetings March 13 at the Northwest Natural Gas Building, Portland, and April 10 at the Sweetbriar Inn, Tualatin, Oregon. These meetings are held at 11:30 a.m. and include lunch and a speaker on topics generally relating to energy interests in the Pacific Northwest. Reservations are required and can be made by calling Shelly at (503) 220-2573. □

Geologic guide for the northern Klamath Mountains—Part I Cow Creek to Red Mountain

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This field guide is the first of three parts published for the Geological Society of America (GSA) premeeting field trip no. 1 of the 1992 Cordilleran section meeting. For part 2 (the remainder of Day 1), see the field guide by Donato immediately following this field guide; and for part 3 (Day 2), see Harper (1989). See Figure 1 of this guide for stops of parts 1 and 2.

INTRODUCTION

The northern Klamath Mountains in Oregon consist entirely of accreted terranes (Silberling and others, 1982) that are parts of broader tectonostratigraphic subdivisions referred to as belts (Irwin, 1964). Each arcuately north- to northeast-trending belt is separated from the adjacent by variably east-dipping thrust faults commonly marked by ultramafic rocks. The belts have complex stratigraphic relations, and evidence for upward younging to the northwest is complicated by faulting and folding. According to Hotz (1971a) and Irwin (1985), the terranes of the western Paleozoic-Triassic belt overlie those of the western Jurassic belt approximately along the thrust fault marked by metamorphosed ophiolitic rocks in the area of this field guide (Figures 2 and 3). The thrust fault, referred to here as the Cedar Springs Mountain thrust, continues south more than 250 km into southern Oregon and northern California (Hotz, 1971a). Jachens and others (1986) estimate 110 km of horizontal displacement along the thrust.

The terranes in the area of this field guide have been mapped regionally (Smith and others, 1982) and in more detail (Kays, 1970; Kays and others, 1988). Rock units of the terranes are referred to informally as Cow Creek arc greenstones and mudstones, Elk Creek ophiolitic rocks, and Wildcat Ridge schists and gneisses (see Figure 3). Cow Creek rocks on the west are structurally lowest and are separated from the overlying Elk Creek ultramafic and amphibolitic rocks on the east by the Cedar Springs Mountain thrust fault. Smith and others (1982) correlate the Cow Creek and Elk Creek rocks with the western Jurassic belt and the Wildcat Ridge unit (easternmost) with the western Paleozoic-Triassic belt. On Day 1 of this field trip, we will traverse all the units, paying special attention to their variations in metamorphic grade and degree of structural complexity. As we shall see, these variations relate to the character and timing of metamorphic and deformational events.

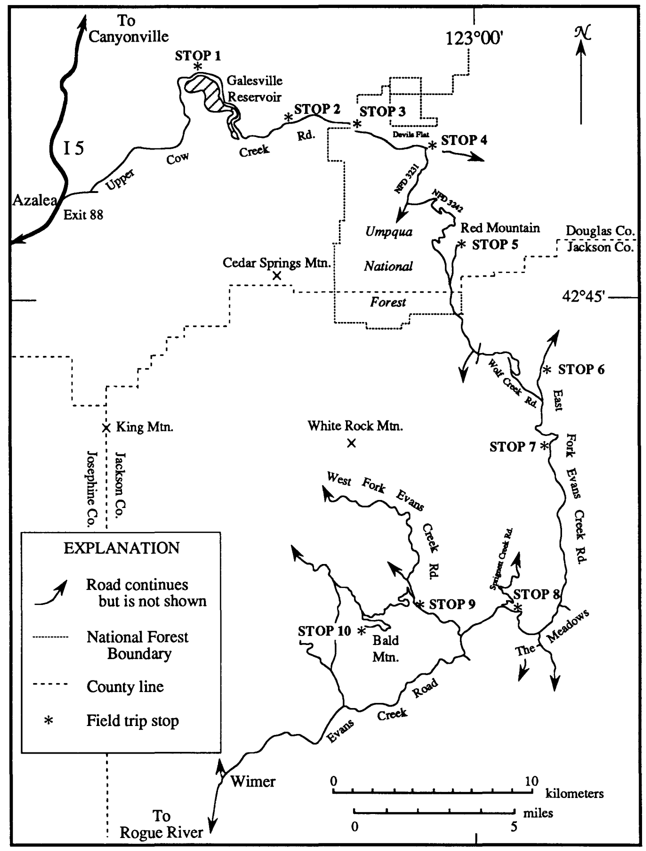

Figure 1. Map showing stops for field trip parts 1 and 2 (Day 1) of premeeting field trip no. 1 of the 1992 Cordilleran section meeting of the Geological Society of America.

TECTONOSTRATIGRAPHIC UNITS

Cow Creek greenstones along the north shore of the Galesville Reservoir near the dam (Stop 1) are flows, breccias, and volcaniclastic andesites-basalts metamorphosed at low grade. Green metatuffs, tuffaceous mudstones, and black, organic-rich mudstones-slates interlayered with the metavolcanic rocks are increasingly abundant 3 to 5 km eastward from the reservoir. Metamorphic grade increases, and fabrics improve in the same direction. Folded black graphitic mudstones-slates (Stop 2) occur on the east beneath the thrust-faulted contact with Elk Creek ophiolitic rocks.

Although offset and locally disturbed by faults, the Cow Creek mudstones, tuffaceous units, and metavolcanic rocks are traceable and locally have recognizable depositional contacts. According to Irwin (1985), the greenstones and mudstones are part of the Western Klamath terrane and the Rogue Valley subterrane (Table 1). In comparison to the descriptions of Wells and Walker (1953) and Garcia (1979, 1982), the Galice Formation fine-grained flysch succession and Rogue Formation metavolcanic rocks are lithologically similar, respectively, to the Cow Creek mudstones and greenstones. Blake and others (1985) indicate that, in the type area, the Galice Formation flysch is depositional on the Rogue Formation tuffs, flows, and volcanic wackes. Thus, the Rogue-Galice relations in the type areas are similar to those of the mudstone-metavolcanic sucession in the Cow Creek sequence (Figure 3). Harper and others (1989) indicate an age range of 150 to157 Ma for the type Galice Formation, whereas Saleeby (1984) reports an age of 157 ± 2 Ma for dacite dikes in the Rogue Formation. Harper and others (1989) and Pessagno and Blome (1990) indicate that the Galice and Rogue Formations are depositional on the Josephine ophiolite, which is also constrained in age (162 ± 1 Ma, U/Pb zircon age of from plagiogranite).

Elk Creek rocks are penetratively foliated ultramafic schists and amphibolites. The amphibolites (Stop 3) are mafic and locally gradational to coarse-grained clinopyroxene-bearing rocks. Traced southwest, the ultramafic rocks and amphibolites of the Cow Creek

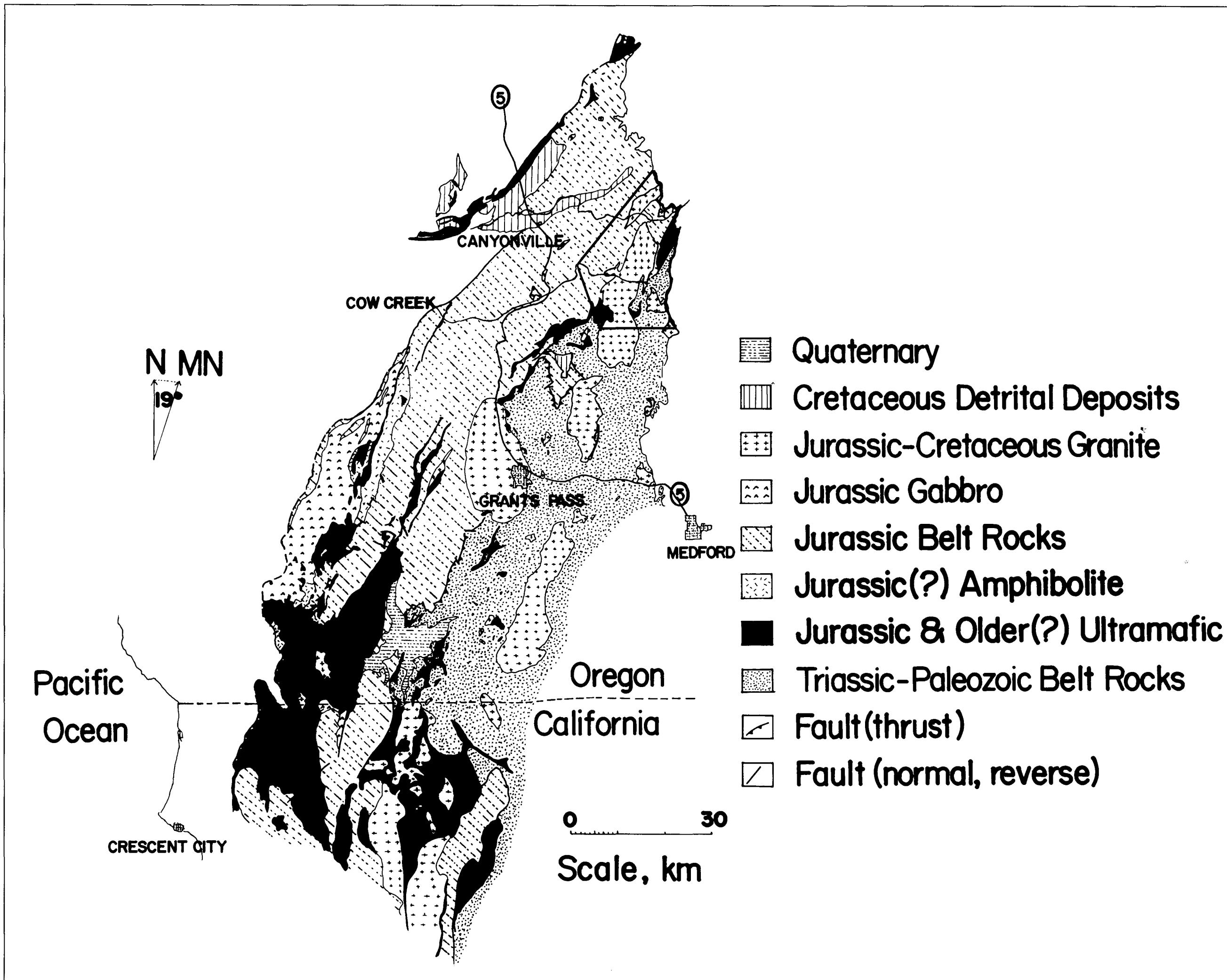

Figure 2. Geologic map, modified from Hotz (1971a), showing geologic units in the western Jurassic and western Paleozoic-Triassic belts in the Klamath Mountains. Circled numbers refer to Interstate 5, which intersects the turnoff eastward on Cow Creek where this field guide begins. The outlined region near the top of the map shows the area under discussion (see text). The northernmost group of Jurassic-Cretaceous plutons (Jurassic-Cretaceous granite) belongs to the White Rock pluton.

area are on line with mapped serpentinized harzburgites, gabbros, diabase dikes, and basalts of the Sexton Mountain area. Smith and others (1982) consider that the ultramafic-mafic suite of Sexton Mountain has "relative" Jurassic age older than the Josephine ophiolite, but no documentation is offered. Irwin (1985) includes Elk Creek rocks with the Rogue Valley subterrane. As we shall see in the following discussion, Elk Creek rock units have textures, structures, and metamorphic characteristics similar to those of the Wildcat Ridge rock units. Elk Creek rocks also occur abundantly as roof pendants and xenolithic rafts within the White Rock pluton. Thus, Elk Creek rocks have questionable terrane affinity, and additional work will be required to properly determine their tectonostratigraphic position.

Wildcat Ridge schists are dominantly mafic, chlorite-actinolite-epidote amphibolites. Locally, there are interlayered quartz-mica and chlorite-quartz schists in addition to narrow belts of tectonically interlayered ultramafic schists. Quartzites and marbles also occur but are rare. The units and their tectonically interlayered nature are similar to those in the Marble Mountains terrane of the western Paleozoic-Triassic belt in the north-central Klamath Mountains (Kays and Ferns, 1980; Mortimore, 1985). The belt extends southward into the Cleveland Ridge quadrangle, where amphibolites are dominant (Smith and others, 1982). All the Wildcat Ridge and Cleveland Ridge rocks have strong metamorphic fabrics. Irwin (1985) correlates these rocks with the May Creek terrane of the Paleozoic-Triassic belt (Table 1). Structurally, the Wildcat Ridge schists are on the downdropped east side of a normal fault that separates these rocks from the underlying Elk Creek ultramafic schists and amphibolites. The normal fault may project into a thrust fault that is largely obscured by intrusion of the White Rock pluton.

White Rock calc-alkaline plutonic rocks intrude Cow Creek, Elk Creek, and Wildcat Ridge rocks. The plutonic rocks are granular, coarse grained, and leucocratic with composition in the range of tonalite-granodiorite-trondhjemite. The more silicic plutonic rocks commonly have white mica and biotite in the mode. Analyzed trondhjemites are peraluminous (2-3 percent normative corundum). The biotite from these rocks gives a corrected K/Ar age of 141 Ma (Hotz, 1971b). The plutonic rocks are only locally foliated (Stop 4), e.g., near contacts with wall rocks and in the vicinity of xenoliths and larger rafts or pendants of the Cow Creek, Elk Creek, and Wildcat Ridge rocks.

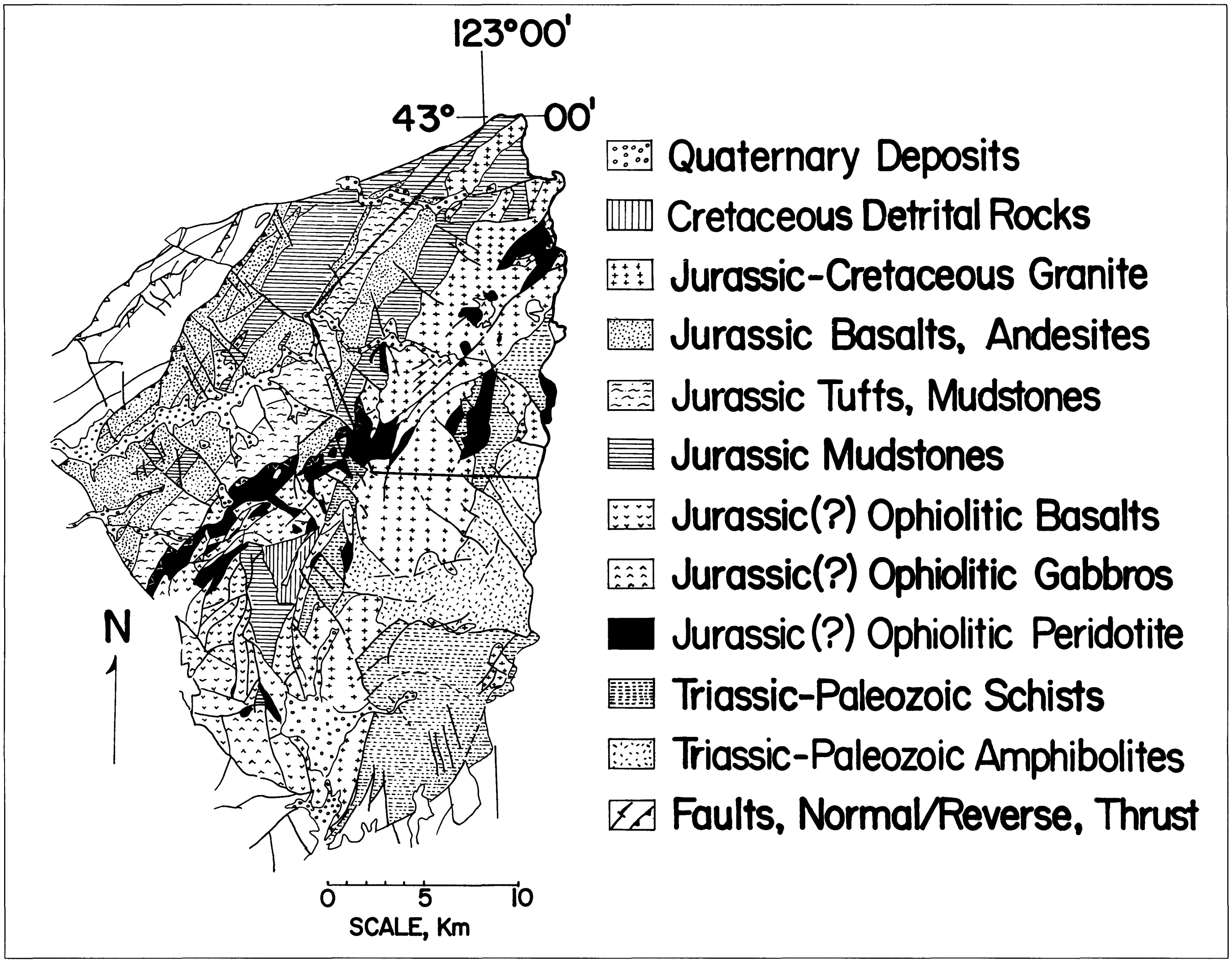

Figure 3. Geologic map for the northern Klamath Mountains, modified in part from Smith and others (1982). The unit "Jurassic-Cretaceous Granite" is referred to in the text as the White Rock pluton. In the area of this field guide (see index boundary), Jurassic basalts, andesites, tuffs, and mudstones are all part of the Cow Creek volcanic-arc mudstone sequence; Jurassic ophiolitic basalts, gabbros, and peridotite are all part of the Elk Creek sequence of rocks; and Triassic-Paleozoic schists and amphibolites are all part of the Wildcat Ridge sequence.

PROGRESSION OF SMALL-SCALE STRUCTURES

D_{1cc}, $D_{1\text{-}2ec}$, and $D_{1\text{-}2wr}$ deformations and related metamorphic structures

The subscripted symbols refer to the conventional ordering of small-scale structures in Cow Creek (cc), Elk Creek (ec), and Wildcat Ridge (wr) rocks. All planar surfaces are referred to by symbol "S," folds by "F," lineations by "L," metamorphic assemblages by "M," and deformations by "D." The metamorphic cleavages/foliations in the three rock groups are all axial planar and are defined relative to the folds that generated them. The earliest recognizable small-scale structure in Cow Creek rocks is well-defined bedding (S_0), which is transposed by penetrative metamorphic cleavage/foliation (S_{1cc}) along the axial planes of outcrop-scale folds (F_{1cc}). The earliest recognizable surface in Wildcat Ridge and Elk Creek rocks is metamorphic layering or cleavage that is transposed in each by a later penetrative metamorphic cleavage/foliation. The subscripts for metamorphic cleavages in Wildcat Ridge and Elk Creek rocks indicate that the earliest foliation assemblage can be distinguished only in the hinge areas of folds, therefore acknowledging that it is not practical to separate these metamorphic surfaces. Therefore, cleavages or foliations in Wildcat Ridge and Elk Creek rocks are termed $S_{1\text{-}2wr}$ and $S_{1\text{-}2ec}$, respectively. These foliations are axial planar to intrafolial folds ($F_{1\text{-}2wr}$ and $F_{1\text{-}2ec}$, respectively) that have millimeter- to centimeter-scale hinges. Overall, the orientations of foliations in Cow Creek (S_{1cc}), Elk Creek ($S_{1\text{-}2ec}$), and Wildcat Ridge ($S_{1\text{-}2wr}$) rocks are parallel. However, because the rock units are separated by faults, cleavages in the separate belts are not necessarily correlative with the same deformation (Table 1).

Quartz-muscovite-chlorite-biotite-feldspars-graphite, and chlorite-actinolite-epidote-plagioclase-oxides ± quartz define the S_{1cc} cleavage in Cow Creek metamudstones-slates and green metatuffs-phyllites, respectively. The cleavage assemblages in Cow Creek black slates and green phyllites record syntectonic M_{1cc} metamorphism. Stop 2 provides an excellent example for observation of metamorphic cleavage (S_{1cc}) that tranposes bedding (S_0) in F_{1cc} fold hinge areas in the black graphitic slates.

Mineral assemblages of Elk Creek foliations ($S_{1\text{-}2ec}$) commonly consist of the following: (1) talc-antigorite-tremolite or talc-olivine-tremolite in ultramafic rocks; (2) actinolitic hornblende-chlorite-plagioclase-epidote/clinozoisite in mafic schists or gneisses, and (3) muscovite-biotite-quartz-graphite-plagioclase ± chlorite in metamudstones. However, $S_{1\text{-}2ec}$ schistosity in ultramafic rocks of the Elk Creek terrane is difficult to recognize because the rocks are commonly crisscrossed by later anastomosing veins of serpentine. The mineral assemblages of Wildcat Ridge foliations ($S_{1\text{-}2wr}$) are similar to those in micaceous and mafic schists of Elk Creek rocks. Recrystallization syntectonic with deformation $D_{1\text{-}2}$ in Elk Creek and Wildcat Ridge rocks is termed $M_{1\text{-}2ec}$ and $M_{1\text{-}2wr}$, respectively.

D_{2cc}, D_{3ec}, D_{3wr}, and related metamorphic structures

Tonalitic-trondhjemitic plutonic rocks (141 Ma, K/Ar on biotite; Hotz, 1971b) intrude foliated rocks of the Cow Creek, Elk Creek, and Wildcat Ridge groups and are in turn folded by F_{2cc}, F_{3ec}, and F_{3wr} folds, respectively. These deformations also fold intruded, thrust-faulted contacts between Cow Creek and Elk Creek rock groups. Porphyroblastic minerals have a prolonged growth range that is pre- and syntectonic with respect to deformations D_{2cc}, D_{3ec}, and D_{3wr}. Andalusite, staurolite, and locally sillimanite are notable in this regard with elongate crystallographic Z-directions aligned approximately parallel with F_{2cc}, F_{3ec}, and F_{3wr} fold axes. Thus, M_{2cc}, M_{3ec}, and M_{3wr} porphyroblastic assemblages appear to represent one thermal episode that overlapped with D_{2cc}, D_{3ec}, and D_{3wr} deformations, respectively, in the three rock groups. Consequently, alignment of porphyroblasts in pelitic schists and finer grained amphibole in amphibolites forms a lineation (L_{2cc}, L_{3ec}, L_{3wr}) in Cow Creek, Elk Creek, and Wildcat Ridge rocks, respectively. A penetrative cleavage/foliation did not form during this recrystallization.

Later structures

All rock units have been broadly folded (F_{3cc}, F_{4ec}, and F_{4wr}, etc., in the Cow Creek, Elk Creek, and Wildcat Ridge terranes, respectively) and were subsequently faulted. These tectonic events are generally unconstrained in age, except where metamorphic rocks are overlain by Upper Cretaceous sedimentary rocks and/or Eocene volcanic rocks of the western Cascades. For example, faults later than latest folding are pre- and post-Western Cascade (Eocene-Oligocene?) deposition.

METAMORPHISM

Structural observations on small-scale structures indicate that metamorphic assemblages in all three terranes are polymetamorphic. The porphyroblastic (M_{2cc}, M_{3ec}, and M_{3wr}) assemblages are independent of boundaries between the Cow Creek, Elk Creek, and Wildcat Ridge rock units (Kays and Rice, 1991).

The mapped facies boundaries shown in Figure 4 are based on mineral assemblages in metapelitic rocks. More detailed subdivision is possible and includes: (1) chlorite, (2) chlorite-biotite, (3) andalusite-biotite-chlorite, (4) andalusite-staurolite-chlorite, and (5) staurolite-sillimanite zones. Zone 1 is broadest and is mostly outside the area of detailed mapping in Figure 4. Within it, assemblages vary from incompletely recrystallized with nonpenetrative fabrics to completely recrystallized slates and phyllites. Assemblages in zones 2-5 are phyllitic to schistose and are illustrated by the use of AFM diagrams (Figure 5). The staurolite-sillimanite zone assemblages are widespread in the area of abundant plutonic rocks and may represent assemblages formed in (now eroded) roof pendants. The structural data seem to confirm this idea. Overall, metamorphic assemblages in the serpentinized ultramafic rocks and in mafic amphibolite gneisses are consistent with those in the metapelites.

INTERPRETATION OF METAMORPHIC ASSEMBLAGES AND SMALL-SCALE STRUCTURES

Metamorphic assemblages form cleavages/foliations S_{1cc}, $S_{1\text{-}2ec}$, and $S_{1\text{-}2wr}$, respectively, in the Cow Creek, Elk Creek, and Wildcat Ridge rock units. These foliations are earlier than the White Rock pluton with a cooling age of 141 Ma (K/Ar on biotite; Hotz, 1971b).

Table 1. *Subdivision of the terranes of the northern Klamath Mountains*

Postamalgamation pluton	Belt	Terrane	Subterrane	Lithotectonic units	Small-scale structures
Jurassic-Cretaceous White Rock pluton (141 Ma, K/Ar on biotite)				Tonalite-trondhjemite-granodiorite with two micas, peraluminous	Locally foliated in xenoliths or roof pendants, syntectonic with F_{2cc}; F_{3ec}, F_{3wr}.
	Western Jurassic belt				
		Western Klamath terrane			
			Rogue Valley subterrane	Cow Creek greenstones-amphibolites, mudstones-slates-schists	S_0; S_{1cc}, F_{1cc}, L_{1cc}; F_{2cc}, L_{2cc}.
	(?)	(?)	(?)	Elk Creek ultramafic schists, amphibolites (terrane affinity still in question)	$S_{1\text{-}2ec}$, $F_{1\text{-}2ec}$, $L_{1\text{-}2ec}$; F_{3ec}, L_{3ec}.
	Paleozoic-Triassic belt				
		May Creek terrane		Wildcat Ridge schists (melange?), amphibolite, chlorite-quartz, quartz-biotite, serpentine-talc-tremolite schists	$S_{1\text{-}2wr}$, $F_{1\text{-}2wr}$, $L_{1\text{-}2wr}$; F_{3wr}, L_{3wr}.

Notes:

—S_{1cc}, $S_{1\text{-}2ec}$ are subparallel to the Cedar Springs Mountain thrust fault separating terranes and lithotectonic units; $S_{1\text{-}2ec}$, $S_{1\text{-}2wr}$ foliations are largely parallel.

—The White Rock pluton intrudes S_{1cc}, $S_{1\text{-}2ec}$, $S_{1\text{-}2wr}$.

—Final recrystallization and porphyroblastic mineral growth was syntectonic with F_{2cc}, F_{3ec}, F_{3wr}, and these assemblages are prograde toward the White Rock pluton.

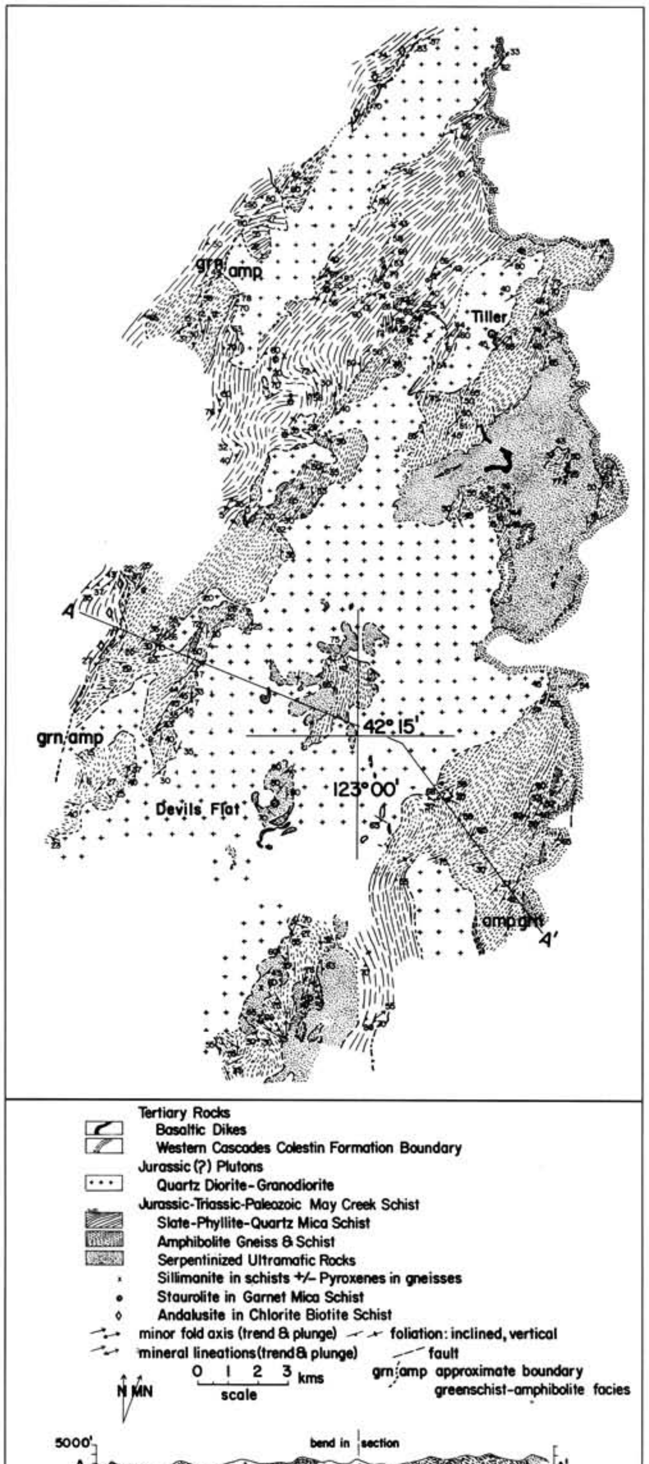

Figure 4. Geologic map for the northern Klamath Mountains, modified from Kays (1970); Kays and others (1988); and later work by Kays. The metamorphic zone boundary indicated as "grn:amp" is approximately the greenschist-amphibolite facies boundary separating assemblages in the andalusite-biotite-chlorite zone from those in the andalusite-staurolite-chlorite zone or the sillimanite-staurolite-biotite zone in metapelitic slates and schists. See Figures 2 and 3 for terrane affinities of the metamorphic map units that are shown here.

However, the cooling age is nearly the same as the magmatic age of the Grants Pass pluton (139 Ma, U/Pb on zircon; Harper and others, 1989), which has a composition and structural positioning that is similar to the White Rock pluton. Correlation of Cow Creek rocks with those of the Galice and Rogue Formations (Smith and others, 1982) with an age range of 150-162 Ma (Harper and others, 1989) makes S_{1cc} foliation younger than this range but older than 141 Ma. Penetrative foliations in the Elk Creek ($S_{1\text{-}2cc}$) and Wildcat Ridge ($S_{1\text{-}2wr}$) metamorphic rocks are also older than 141 Ma but transpose an even older metamorphic fabric. These relations indicate that if Cow Creek metamorphism (M_{1cc}) is Nevadan (older than 141 Ma and younger than 150-160 Ma), then the earliest unconstrained Elk Creek and Wildcat Ridge metamorphic fabrics could be pre-Nevadan (Siskiyou event of Coleman and others, 1988). Penetrative Elk Creek and Wildcat Ridge foliations are also unconstrained with regard to their maximum age. However, Donato and Lanphere (1992) have recently obtained a U/Pb zircon age of approximately 154 Ma on diorite that intrudes an amphibolite unit structurally below the May Creek Schist in the western Paleozoic-Triassic belt south of Wildcat Ridge. The suggestion is that metamorphic foliation in the Wildcat Ridge rocks, which Irwin (1985) assigns to May Creek terrane (western Paleozoic-Triassic belt), could be "earliest" Nevadan or pre-Nevadan.

Field and petrographic data suggest that the final prograde metamorphic event included a porphyroblastic growth stage that was achieved by overprinting the minerals that formed penetrative cleavage/foliation. Furthermore, this porphyroblastic recrystallization (termed M_{2cc}, M_{3ec}, and M_{3wr} in Cow Creek, Elk Creek, and Wildcat Ridge rocks, respectively) overlapped with isoclinal (F_{2cc}, F_{3ec}, and F_{3wr}) folding. Equivalence of these metamorphisms indicates a metamorphic field gradient for the last metamorphic event that proceeded along a prograde, low-pressure path largely in the andalusite stability field. The path crossed into the sillimanite field at pressures less than the triple point for the Al_2SiO_5 polymorphs (about 3.8 kbars). The narrow width of mapped metamorphic zones in the andalusite field suggests a rapidly rising temperature that culminated in a broader amphibolite facies (staurolite-sillimanite zone) in more abundantly intruded rocks (Figure 4).

As noted in the discussion of small-scale structures, porphyroblastic growth that overlapped with F_{2cc}, F_{3ec}, and F_{3wr} folding was synchronous with or followed intrusion of tonalite-trondhjemite plutons in the region. The chronology of structures and assemblages and their distribution argues in favor of a regional, prograde sequence that formed later than the Cedar Springs Mountain thrust. Furthermore, assemblages in metapelites and their progression are not the same as the kyanite-sillimanite or andalusite-sillimanite baric types. The suggestion is that the assemblages are representative of an intermediate metamorphic path that is typical of metamorphism in the northern Klamath Mountains of Oregon. The cooling age (141 Ma, K/Ar on biotite; Hotz 1971b) for the White Rock pluton indicates that this metamorphism is Nevadan.

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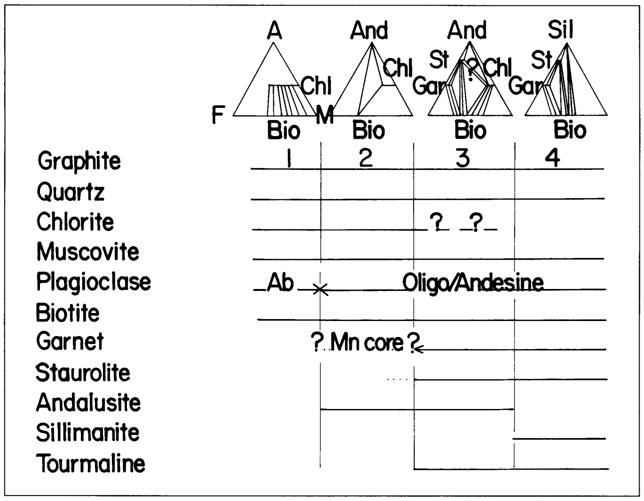

Figure 5. Metamorphic assemblages in metapelitic slates and schists in the northern Klamath Mountains. Zones 1 and 2 are greenschist facies; zones 3 and 4 are amphibolite facies.

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FIELD LOG—DAY 1, PART 1, COW CREEK TO RED MOUNTAIN

For the GSA field trip, a handout log without details is provided for the transit along Interstate 5 to the start of the guided field trip. General geology for the log on Interstate 5 is from Ramp (1972). For stops on Day 1, see Figure 1.

Milepoint 0.0—Start. Field log for Day 1 begins at intersection of Interstate 5 with Cow Creek Road (107.2 mi from Eugene) after taking Azalea Exit 88 going east to Galesville Reservoir.

7.2—Stop 1. Galesville Reservoir pullout on right. The Cow Creek terrane low-grade green metatuffs and volcaniclastic breccias are considered equivalent in age to the Upper Jurassic Rogue and Galice Formations (Smith and others, 1982). Deformation is by brittle cataclasis but may be ductile-brittle in the metatuffs. Tensional veins in the volcaniclastic rocks are filled with clinozoisite fibers. The fibers are aligned parallel to shear planes with orientation N. 6° E., 53° SE. Fiber alignment and shear planes are at high angle to tensional veins. Shear sense is top to west.

12.6—Stop 2. Well-exposed outcrop-scale folds (F_{1cc}) of Cow Creek mudstone-slate with penetrative axial planar cleavage (S_{1cc}). The cleavage assemblage is muscovite-quartz-chlorite-graphite ± albite and transposes bedding (rhythmic organic mudstone-quartzose siltstone layers). The F_{1cc} fold axes are N. 3° E. to N. 35° E., plunging 11° to 18°. The folds are faulted. The S_{1cc} cleavage is folded by smaller scale folds (F_{2cc}). Folds of bedding (S_0) distinguish Cow Creek mudstones from Elk Creek and Wildcat Ridge rocks.

15.1—Stop 3. Elk Creek terrane amphibolite gneiss outcrop and borrow pit for road rock. The rock is composed of medium-grained amphibole, plagioclase (An_{22}), and lesser amounts of sphene and/or rutile and clinozoisite-epidote. Note that there are abundant small-scale, sheared, intrafolial ("fish-hook" F_{1-2ec}) folds. The wavelengths of the sheared F_{1-2ec} folds are several millimeters to a centimeter in the hinge areas. The folds trend N. 25° E. to N. 35° E. and plunge 0° to 35°. Penetrative S_{1-2ec}

foliation is axial planar to the intrafolial folds and transposes earlier, poorly defined cleavage or foliation and feldspar-quartz segregation veins. The veins when folded form ptygma that also define $F_{1\text{-}2ec}$ hinges. Locally, there are larger scale F_{3ec} isoclinal folds of foliation. Note the contrast between the style of $F_{1\text{-}2ec}$ and F_{1cc} folds (Stop 2).

17.6—STOP 4. Coarse-grained, two-mica granodiorite with well-developed foliation (approximately N. 10° E., 40° SE.) that consists of mica, quartz, and feldspar alignment and a slight segregation of biotite. Larger feldspar grains are augen shaped, and there are crushed quartz and feldspar grains indicating shearing. See especially the large xenoliths of serpentinized peridotite and amphibolite gneiss and the foliation in the gneiss (N. 25° E., 35° SE.) subparallel to that of granodiorite. See also the broken fold in the amphibolite with an upper sheared limb to the west.

18.0—Devils Flat picnic area (turn left over cattle guard). Lunch stop for GSA field trip. Those who are interested may continue 0.2 mi east on Upper Cow Creek Road for a closer look at the granodiorite and its locally abundant xenoliths. At this location we are well inside the pluton and the foliation here, in contrast to that recognized in the granodiorite at Stop 4, is poor except immediately adjacent to the larger xenoliths of amphibolite and serpentinized peridotite. The trend of the foliation in the xenoliths is generally concordant with that of metamorphic rocks adjacent to the pluton, although it is clear that plutonic rocks intrude the metamorphic foliation.

After lunch stop at Devils Flat, turn around and drive back about 0.4 mi to Stop 4 and then turn left (south) onto Applegate Creek Road.

17.6—Continue south on Applegate Creek Road or NFD (National Forest Road) 3231, traveling through weathered granodiorite with large and small rafts of serpentinized peridotite, amphibolite, and occasional biotite-rich schist.

19.7—Turn left at road intersection with NFD 3242 to Red Mountain and stay on 3242. The road cuts are mainly granodiorite with xenoliths of ultramafic rocks, schist, and amphibolite of the Elk Creek terrane for the first approximately 1.2 mi, until we reach the contact between metamorphic and plutonic rocks.

26.3—Continue along NFD 3242 in ultramafic rocks and occasional amphibolite to the next road intersection.

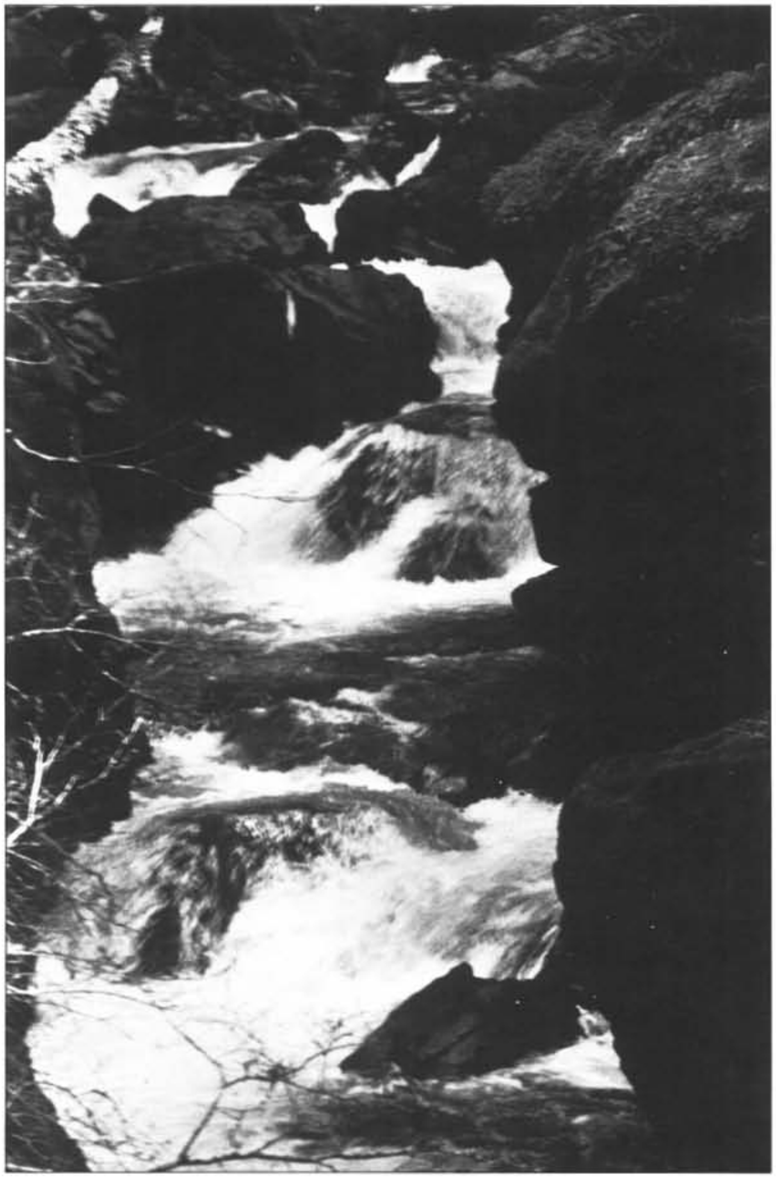
27.8—Turn left at road intersection NFD 3242 and spur road 230 to Red Mountain. The rocks at the intersection are sheared talc-tremolite serpentinites with a spaced cleavage parallel to shear planes.

28.0—Road metal quarry in massive serpentinite. Just ahead there are mafic metasomatized (rodingitic?) amphibole-rich "dikes" in the serpentinite.

29.2—Stop 5. Former site of Red Mountain Lookout, where serpentinized peridotite and amphibolite are in contact. The contact trends approximately NS to NW and may be a recrystallized and subsequently folded thrust. The peridotite consists of (approximately 10- x 40-cm) phacoidal blocks that are bounded by anastomosing veins of sheared talc-tremolite serpentinite. Internally, the peridotite has penetrative cleavage caused by preferred orientation or alignment of antigorite and talc and lesser amounts of chlorite and tremolite. The cleavage is interpreted to be $S_{1\text{-}2ec}$ but is easily modified or disturbed and in some places obliterated by the anastomosing veins. In some places the veins are planar shear zones centimeters to several centimeters thick and form a spaced cleavage (N. 57° E., 72° SE.) that transposes $S_{1\text{-}2ec}$ in the peridotite. The amphibolite is amphibole rich with 1 mm thick or less lensoidal plagioclase- and amphibole-rich bands. The banding and flattened amphibole grains constitute $S_{1\text{-}2ec}$.

Return 1.2 mi to intersection of NFD 230 and NFD 3242 for part 2 of the field trip (discussion by Donato, next page).

Field trip continues on next page →



Cow Creek Gorge at Devils Flat. This is the area of the lunch stop for the Klamath Mountains field trip that is premeeting field trip 1 of the 1992 Cordilleran Section meeting of the Geological Society of America. Photo courtesy of Jim Hines, Tiller Ranger Station, Umpqua National Forest, USDA Forest Service.

Geologic guide for the northern Klamath Mountains—Part 2
Red Mountain to Bald Mountain (May Creek Schist and related rocks)

by Mary M. Donato, U.S. Geological Survey, MS 910, 345 Middlefield Road, Menlo Park, California 94025

INTRODUCTION

The second part of this field trip highlights selected localities in amphibolite-facies metabasites (amphibolites) and structurally overlying metasedimentary rocks known as the May Creek Schist (usage of Donato, 1991b). The route generally traverses the area from north to south and from lower to higher structural levels, beginning in amphibolite and ending in mylonitic May Creek Schist.

The amphibolite and the May Creek Schist crop out in the northeasternmost part of the Klamath Mountains and are part of Irwin's (1966) western Paleozoic and Triassic belt, although this name probably does not accurately describe the age of these rocks (see below). Their location and distribution are shown in Figure 1. These units are noteworthy because they are distinctly higher grade than the predominantly greenschist-facies rocks in this part of southwestern Oregon. Most contacts with adjacent units are faults, or they are obscured by intrusive bodies.

Neither the protolith age nor the metamorphic age of these rocks is well known, but a few constraints are available. The White Rock pluton (141 Ma; K/Ar, biotite; Hotz, 1971) clearly intrudes and contact-metamorphoses the amphibolite. The Wimer pluton, which intrudes both the May Creek Schist and the amphibolite, is undated but may be similar in age to the nearby Grants Pass pluton (139 Ma; Saleeby, 1984).

Initial $^{40}Ar/^{39}Ar$ incremental heating studies on metamorphic hornblendes from the amphibolite suggested a so-called Nevadan cooling age of approximately 145 Ma (Donato, 1991a), but continuing work has yielded plateau ages ranging from approximately 111 Ma to approximately 162 Ma (Donato, unpublished data). A syntectonic hornblende diorite that concordantly intrudes, contact-metamorphoses, and engulfs xenoliths of amphibolite near the contact with the May Creek Schist gives igneous (Pb/U, zircon; Richard Tosdal, U.S. Geological Survey, written communication, 1991) and cooling ($^{40}Ar/^{39}Ar$, hornblende; Donato, unpublished data) ages of approximately 154 Ma and 153 Ma, respectively. Contact relations and textures suggest that emplacement of the diorite postdated or was synchronous with the later stages of metamorphism and deformation of the amphibolite. The diorite exhibits "hot-worked" narrow shear bands composed of polygonized hornblende and plagioclase, which indicates that it continued to be deformed at high temperature after its emplacement (see Stop 9, below). Clearly, the amphibolite and related intrusive rocks have complicated thermal and deformational histories, and resolving them will require further work.

AMPHIBOLITE

The unnamed amphibolite that structurally underlies the May Creek Schist (Figure 2) consists primarily of dark-greenish-gray to black, well-foliated and lineated hornblende-plagioclase schist and gneiss. Although the amphibolite is typically strongly deformed, relict igneous textures are preserved locally in less deformed rocks. Note, however, that all rocks discussed here are thoroughly metamorphosed and recrystallized.

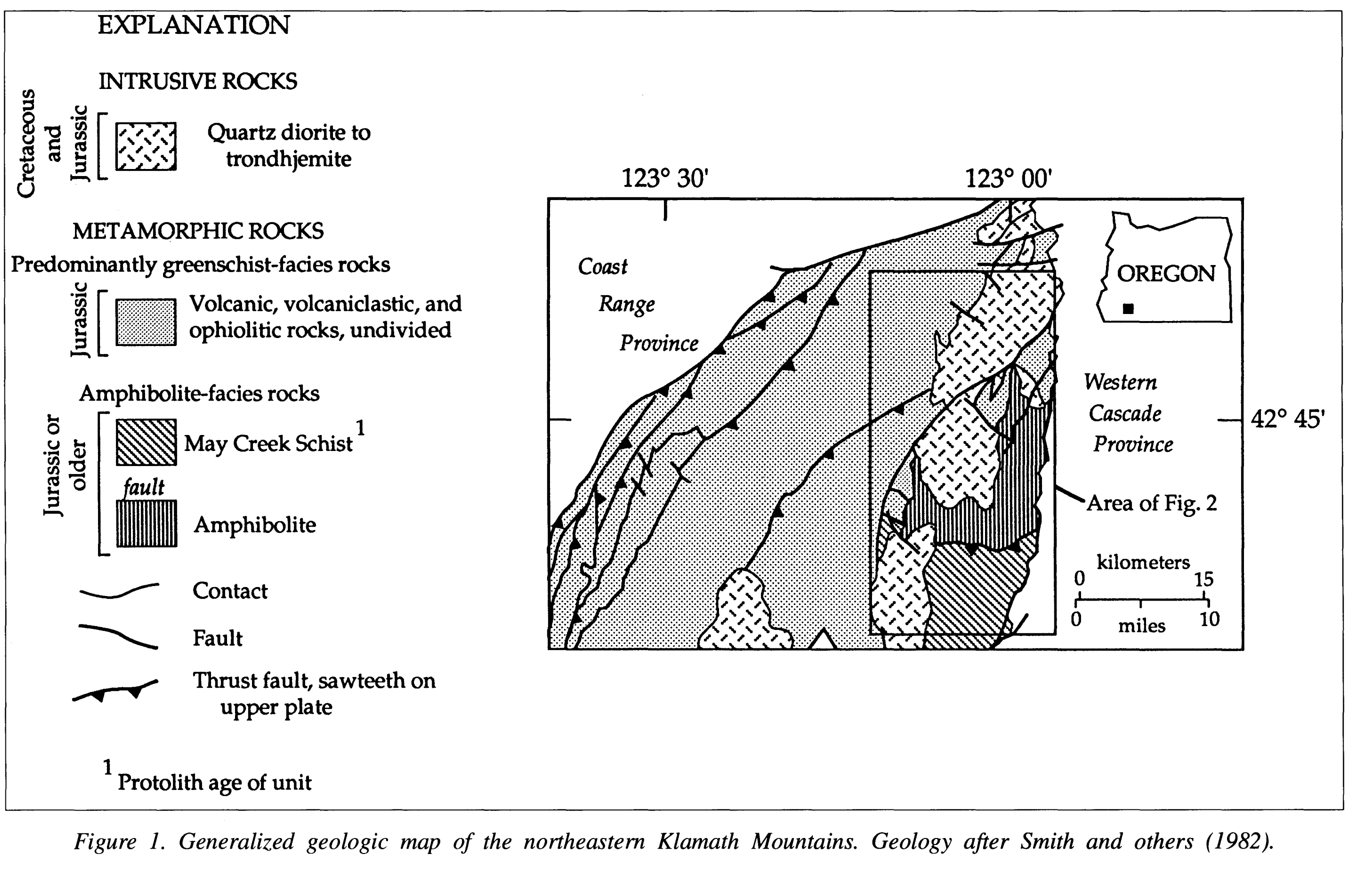


Figure 1. Generalized geologic map of the northeastern Klamath Mountains. Geology after Smith and others (1982).

In addition to the abundant "common" amphibolite (amphibole schist), several textural varieties of amphibolite, including metaporphyry, metadiorite, and metagabbro (so named for their apparent igneous protoliths) have been recognized. In places, tabular bodies of different textural varieties (e.g., metaporphyry vs. metadiorite) are separated by sharp planar contacts, which suggests that they are metamorphosed sheeted dikes or sills (examples at Stops 6 and 7).

All varieties of amphibolite have essentially the same mineralogy: magnesio-hornblende + intermediate plagioclase + accessory sphene ± Fe-Ti oxide. Chlorite and epidote are rarely observed; garnet is absent. Middle-amphibolite-facies metamorphic temperatures and low to moderate pressures are indicated. More complete descriptions of the various types of amphibolite are given in Donato (1991a; 1991b).

The amphibolite contains structurally concordant, massive to schistose bodies of metamorphosed ultramafic rocks (metaserpentinite) that range in size from less than 1 m to 2-3 km in largest dimension. Mineral assemblages include olivine + antigorite + chlorite + opaque oxide (probably magnetite) and olivine + tremolite + chlorite, thus indicating that the ultramafic rocks are the same metamorphic grade as the enclosing amphibolite. Indeed, blackwall (chlorite-talc-magnetite) rinds around metaserpentinite suggest that metamorphism of amphibolite and serpentinite was synchronous. No metamorphosed rodingites were found, however, which suggests that the ultramafites were tectonically incorporated as serpentinites and were not serpentinized *in situ*.

The geochemical characteristics, particularly trace-element compositions, of the amphibolite are very similar to those of present-day oceanic basalts, particularly basalts erupted in back-arc basins (Donato, 1991b). The oceanic geochemical signature of the amphibolite and its present structural position east of Jurassic arc volcanic and volcaniclastic rocks together suggest that the amphibolites formed in a back-arc basin environment.

The amphibolites are L-S tectonites with a pervasive schistosity or foliation defined by alternating hornblende- and plagioclase-rich layers. The foliation generally dips southeast, although it is broadly warped on regional and local scales. A strong, consistent, southeast-plunging hornblende lineation is also present throughout. In some cases, elongate, recrystallized plagioclase grains or aggregates define a measurable flattening plane or, rarely, a stretching lineation parallel to the hornblende lineation. Foliation and lineation in the amphibolite become more pronounced near the contact with the overlying May Creek Schist, but shear criteria and textural evidence of intense ductile deformation and dynamic recrystallization are best developed in the basal, quartzose part of the May Creek Schist.

Rare outcrop-scale isoclinal reclined folds deform the foliation. These folds generally plunge southeast, parallel to the hornblende lineation and parallel to stretching lineations measured in metasedimentary rocks from the ductile shear zone; the axial planes of reclined folds are parallel to the measured foliation.

MAY CREEK SCHIST

Mica schist and mica slate considered to be Devonian(?) in age and located near the town of Wimer, Oregon, were named the May Creek Formation by Diller and Kay (1924). Today the name "May Creek Schist" refers to rocks corresponding in part to Diller and Kay's (1924) May Creek Formation (see Donato, 1991b). The May Creek Schist structurally overlies the amphibolite along a ductile shear zone, described below. The nature of the original contact is unknown, but the protolith of the May Creek Schist may have been deposited directly on the basaltic protolith of the amphibolite.

The May Creek Schist shows considerable compositional variety. The lower structural levels are generally quartz rich and include nearly pure quartzite, quartz-biotite schist, and quartzofeldspathic schist, consisting mainly of quartz, feldspar, biotite, and white mica with accessory garnet, tourmaline, opaque oxides, and amphibole. Calcareous schists containing quartz, clinozoisite, sphene, and calcite are also present. At higher structural levels (mostly south of Evans Creek; not covered by this road log), schists are less siliceous, are more amphibole- and biotite-rich, and contain apparent volcanic detritus as well as more abundant calcareous material. Petrographic examination of these rocks shows abundant plagioclase along with biotite, quartz, amphibole, diopside, and accessory amounts of distinctive rose-colored sphene. Potassium feldspar (microcline) is abundant in some samples.

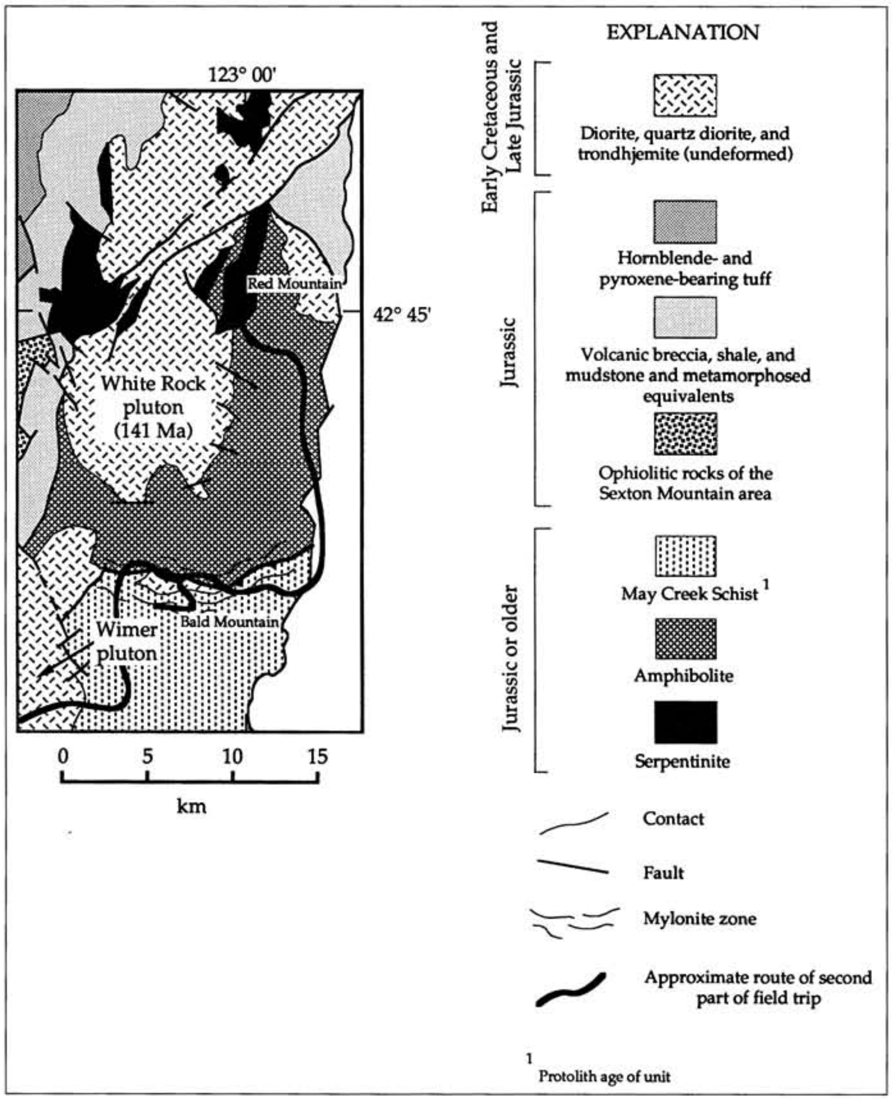


Figure 2. Simplified geologic map showing part of the May Creek Schist and underlying amphibolite in the area covered by the road log. Heavy black line shows approximate route taken by this part of the field trip. Refer to map in companion paper by Kays (above, page 27) for complete route. Geology after Smith and others (1982) and Donato (1991b).

Diagnostic metamorphic mineral assemblages are rare in the metasedimentary rocks in this area. Sillimanite occurs with quartz, plagioclase, biotite, garnet, and white mica at two known localities. Lensoidal aggregates of white mica in samples close to plutonic bodies may represent former contact-metamorphic andalusite or staurolite porphyroblasts. No regional metamorphic andalusite or staurolite was observed in this area, but this lack may only reflect bulk rock composition. In the more calcic tuffaceous rocks higher in the section, diopside coexists with plagioclase, quartz, amphibole, biotite, and calcite. Attempts to establish metamorphic temperatures in four samples of pelitic rocks by using garnet-biotite geothermometry yielded inconsistent results ranging from near 550 °C to nearly 900 °C, with most determinations in the 550° to 650° range (Donato, 1991b). Therefore, although it is impossible to closely constrain temperature and pressure with the available assemblages, middle amphibolite-facies conditions are generally indicated.

The May Creek Schist is everywhere well foliated but is strongly lineated only near its base where it has undergone intense ductile deformation. In pelitic, semipelitic, and psammitic varieties, foliation is defined by alternating micaceous and quartzofeldspathic layers and by flattened lensoidal aggregates of plagioclase or mica. Rocks within the ductile shear zone display a conspicuous lineation caused by elongated quartz, feldspar, and mica grains within the foliation plane. Structural elements such as foliation and lineation in the May Creek Schist are generally parallel to those in the amphibolite (Donato, 1990 and in preparation).

DUCTILE SHEAR ZONE

A zone of ductilely deformed quartz-mica schist and quartzofeldspathic gneiss marks the basal part of the May Creek Schist and indicates northwestward transport of the May Creek Schist over the amphibolite (Donato, 1990 and in preparation). The ductile shear zone trends approximately east-west, is estimated at two localities to be approximately 800 to 1,500 m thick, and is traceable along strike for about 13 km (Figure 2). The rocks in this zone are "mylonitic," according to the criteria adopted by Tullis and others (1982): (1) they have undergone grain size reduction, (2) occur in a relatively narrow planar zone, and (3) display enhanced foliation and lineation due to strain concentration.

Field evidence for mylonitization includes a strong south- to southeast-dipping laminar foliation as well as a pronounced southeast-plunging lineation that is defined by aligned mica flakes and stretched quartz and plagioclase feldspar grains. In quartzofeldspathic rocks, comminuted and broken feldspar porphyroclasts are visible on surfaces that expose the XZ plane of the strain ellipsoid. Good examples of such textures are visible in outcrops on Bald Mountain (Stop 10) and can also be seen in Sprignett Creek and in several places in West Fork Evans Creek between Devil's Garden and the confluence with East Fork Evans Creek. Thin sections of rocks cut in the XZ plane commonly display a beautiful fluxion structure. Plagioclase grains are blocky or subrounded and occasionally broken, whereas quartz has deformed ductilely, flowing around the resistant plagioclase grains and forming elongate ribbons up to 5 mm long (Figure 3).

Mylonitic metasedimentary rocks are only locally in direct contact with the underlying amphibolites. The 154-Ma syntectonic diorite is one of several small intrusive bodies emplaced within or near the contact zone, which suggests that the high-temperature shear bands observed within the diorite could also have been formed during mylonitization. Other strongly deformed rocks, including metaserpentinite, Ca-metasomatic rocks, and smaller dioritic intrusive bodies occur within the zone of ductilely deformed rocks. For example, in the West Fork of Evans Creek, mylonitic quartzofeldspathic schist is tectonically interlayered with lenses of sheared metaserpentinite, talc-tremolite schist, thinly layered quartzite, hornblende-biotite schist, hornblende-epidote schist, mylonitic quartzite, gneissic hornblende diorite, and mylonitic amphibolite. The structural thickness of the tectonically disrupted zone at this locality is about 1,500 m. A similar zone of interlayered ultramafic and mafic intrusive rocks separating amphibolite from mylonitic quartzofeldspathic gneisses is exposed in Sprignett Creek. There, the zone is probably only 600-800 m thick.

Oriented thin sections of mylonitic rocks of the May Creek Schist were examined to determine the sense of shear. Kinematic indicators, including S-C fabrics, mica "fish," and rotated tourmaline and plagioclase porphyroblasts in micaceous quartzofeldspathic schist consistently show top-to-the-northwest sense of shear, indicating northwestward transport of the May Creek over amphibolite (Figure 3). In addition, quartz c-axis petrofabric analysis demonstrates top-to-the-northwest sense of shear in eight of 12 localities (the remaining four display strong lattice preferred orientation but cannot be used to interpret sense of shear). Sillimanite occurs with biotite in the deformed micaceous "tails" of an asymmetric rotated tourmaline porphyroblast in a sample also containing quartz, feldspar, and garnet, clearly indicating that metamorphic conditions during the ductile deformation were within the amphibolite facies. This fact, together with the concordance of structures and metamorphic grade between the amphibolite and May Creek and the lack of petrographic evidence for multiple metamorphic episodes, suggests that the north-

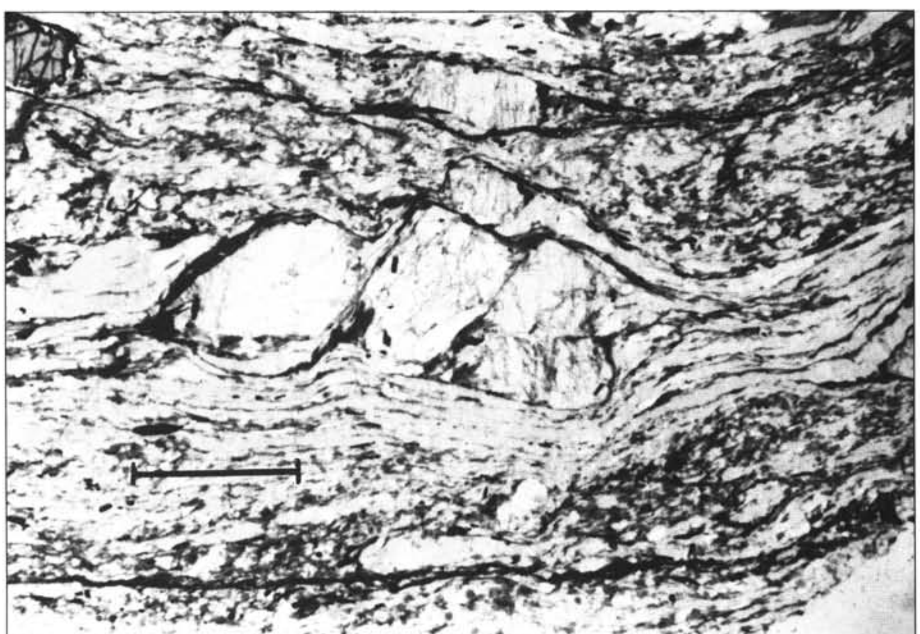


Figure 3. Photomicrograph of broken and rotated plagioclase porphyroblast in mylonitic quartzofeldspathic sample of the May Creek Schist. Three fragments of plagioclase are tilted to the right, indicating dextral sense of shear. Textural evidence such as this together with quartz petrofabric analysis indicates that the May Creek Schist was thrust northwestward over the amphibolite. Biotite and garnet (high-relief mineral in upper left) are also present. Scale bar represents 1 mm.

westward thrusting of the May Creek occurred at the culmination of a single amphibolite-facies metamorphic/deformational event.

SUMMARY

The available petrologic, structural, and geochronologic data for the May Creek Schist, the underlying amphibolite, and associated intrusive rocks allow the construction of a tentative tectonic model for their origin. The geochemistry of the metabasaltic rocks suggests that their protoliths originated in an extensional back-arc basin (Donato, 1991a). These mafic rocks may have formed the oceanic basement upon which clastic sediments, now represented by the May Creek Schist, were deposited. The age of this basin is poorly constrained but must be greater than 154 Ma, the age of the diorite which intrudes the amphibolite. The location of the basin may have been not far from the North American continent, a conclusion based on the abundance of quartz- and feldspar-rich sediments in the lower (older?) parts of the May Creek Schist. Volcanic debris became increasingly abundant as a volcanic arc encroached upon the basin, as represented in the middle and upper parts of the May Creek Schist.

At some time prior to 154 Ma, this basin underwent a compressional event that produced amphibolite-facies metamorphism and folding of the basalts and the overlying sedimentary rocks. Emplacement of serpentinite bodies as tectonic slivers probably occurred at this time. The oldest cooling age thus far obtained from the amphibolite, about 162 Ma, may be a vestige of this event. The 154-Ma diorite must have been emplaced after the inception of this tectonism, because it contains foliated amphibolite xenoliths and produced contact-metamorphic assemblages in adjacent amphibolite; but it could have been partly synchronous with this event, since high-temperature shear bands in the diorite suggest that deformation continued while the intrusion was still hot.

The basin may have collapsed soon after its inception, while the regional heat flow was still high. No obvious localized heat source for amphibolite-facies metamorphism is evident, but if the basin was still young when compression began, temperatures might have been sufficient to account for the high metamorphic grade that is presently seen in the amphibolite and the May Creek Schist and conspicuously absent from the adjacent Rogue and Galice Formations and the Applegate Group. The compression, collapse, and tectonic burial of the still-young and hot basin may have marked its accretion to North America, culminating in the northwestward thrusting of the sedimentary sequence (now called the May Creek Schist) over its igneous (now amphibolitic) basement. This event probably ended during the earliest stages of the so-called Nevadan orogeny in the Klamaths, believed to have lasted from about 155 Ma to 135 Ma (Harper and others, 1989). The 145-Ma and younger cooling ages from the amphibolite suggest that some of these rocks were thermally affected by later so-called Nevadan and younger tectonism and magmatism. The thermal history of this region appears to be complex and bears further investigation.

ACKNOWLEDGMENTS

This paper benefitted from helpful reviews by Russ Evarts and Lynne Fahlquist. Bob Murray recorded mileages, took notes, and provided good company during the construction of the road log.

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ROAD LOG—DAY 1, PART 2, RED MOUNTAIN TO BALD MOUNTAIN

Begin in sec. 26, T. 32 S., R. 3 W., southeast corner of the Cedar Springs Mountain 7½-minute quadrangle, at the intersection of National Forest Road (NFD) 230 and NFD 3242. The mileage between points is followed by cumulative mileage in parentheses.

Milepoint 0.0 (0.0)—Start. Quarry in serpentinite. If travelling down from Red Mountain, make a sharp left turn at the intersection and proceed south on NFD 3242. This road becomes BLM Road 33-3-12.2.

1.3 (1.3)—Umpqua National Forest boundary (leaving National Forest). Enter Skeleton Mountain 7½-minute quadrangle.

1.6 (2.9)—Intersection. Take Road 33-3-12.1 eastward (**NOT** southward!). Enter Cleveland Ridge 7½-minute quadrangle.

0.6 (3.5)—Intersection. Bear right on Road 33-2-7.2 and proceed downhill.

2.0 (5.5)—Road 33-2-7.2 meets the Wolf Creek Road (33-2-17). Make a sharp left turn and proceed downhill past many good road cuts in amphibolite.

1.5 (7.0)—Old borrow pit in amphibolite on right. Bridge across the East Fork of Evans Creek.

0.2 (7.2)—Intersection with East Fork Evans Creek Road (33-2-33). Turn left.

1.5 (8.7)—Stop 6. Quarry in amphibolite. This terraced rock quarry has good exposures of metabasites displaying a variety of relict igneous textures visible both in place and in boulders that were blasted from the quarry walls. One can see examples of relict porphyritic textures and intrusive contacts of what may have been sills or dikes. Because many of the rocks are massive and appear to have little directional fabric, they closely resemble fine-grained mafic intrusive rocks. Locally developed hornblende lineation and foliation and textures observed in thin section confirm that these are in fact amphibolite-facies meta-igneous rocks. They contain hornblende, plagioclase, and sphene or rutile.

Turn around and proceed south on East Fork Evans Creek Road.

1.4 (10.1)—Intersection with Road 33-2-17. Continue straight on East Fork Evans Creek Road.

0.7 (10.8)—Tectonic slivers of talc schist within amphibolite are present in road cuts on the left.

1.7 (12.5)—Stop 7. Near the confluence of the East Fork Evans Creek and Coal Creek. Park in the turnout on the right side of the road just after crossing culvert. Cross the East Fork Evans Creek (carefully, since rocks may be wet and slippery) to see good three-dimensional creekside exposures of interlayered fine- and coarse-grained amphibolite with relict igneous textures. Contacts between "porphyritic" and "aphanitic" varieties are sharp and concordant with the foliation. Some relict plagioclase "phenocrysts" are more than 1 cm long. Outcrop contains felsic veins and segregations, some of which are concordant with the foliation; others are ptygmatically folded. Look closely for small-scale crinkle folds of the foliation.

1.3 (13.8)—Intersection with BLM Road 33-2-33.4. Stay on and continue downhill on East Fork Evans Creek Road. The road crosses the (high-angle?) fault zone marking the contact between amphibolite and Tertiary volcanic and volcaniclastic rocks in this area.

0.1 (13.9)—Sheared and altered Tertiary volcanic rocks.

0.5 (14.4)—Intersection of East Fork Evans Creek Road and road along Chapman Creek. Continue southward on East Fork Evans Creek Road.

0.9 (15.3)—Morrison Creek Road merges from the right with East Fork Evans Creek Road. Continue southward on East Fork Evans Creek Road. In about 1.3 mi, enter Boswell Mountain 7½-minute quadrangle.

3.7 (19.0)—Intersection. Turn right (west), continuing on East Fork Evans Creek Road.

1.3 (20.3)—Stop 8. Park on the right-hand shoulder, completely off the road. This is a narrow, curvy road, so please watch out for traffic. Walk ahead about 0.2 mi to road cuts in quartzite of the May Creek Schist. Since the last stop, we have crossed southward from amphibolite into the structurally higher May Creek Schist, here ranging from foliated quartz-biotite-feldspar-garnet schist to massive, ringing quartzite. Orange-pink color of garnets reflects their Mn- and Ca-rich composition. Quartz in massive quartzite has undulose extinction, but most rocks here are relatively weakly deformed and do not display the mylonitic textures seen elsewhere in the basal part of the May Creek Schist.

0.8 (21.1)—Sprignett Creek Road (34-2-18). This road leads generally northward up a hillside and to a saddle, through many good road cuts in ductilely deformed rocks of the May Creek Schist, metaserpentinite, and amphibolite. This is a good route by which to traverse the ductile shear zone that marks the contact between the amphibolite and the May Creek Schist.

0.8 (21.9)—Entering Skeleton Mountain 7½-minute quadrangle.

0.8 (22.7)—Intersection with West Fork Evans Creek Road (34-3-24). Turn right and proceed upstream. Road cuts on right side of road are quartzites and quartz-mica schists of the May Creek Schist. (Note that some land along the creek is privately owned and is clearly posted "No Trespassing." Please respect the rights of property owners in this area).

0.9 (23.6)—Large parking area on left side of road is the site of a former County maintenance station. There is a path leading down to Evans Creek, where outcrops of folded, well-lineated quartz-mica schist can be seen. By walking downstream, one can also see tectonic slivers of sheared and metasomatized ultramafic rocks interlayered with strongly deformed metasedimentary rocks.

1.0 (24.6)—Stop 9. Bridge over the West Fork Evans Creek. Park on wide shoulder on west (left) side of road and south side of bridge. (Look ahead for oncoming traffic before you make this turn.) Excellent exposures of fresh syntectonic hornblende diorite can be seen across the road in the prominent road cut and, if the water is not too high, in creekbed exposures just beneath and upstream from the bridge. Road cut exposures are massive to locally foliated and lineated, medium- to coarse-grained hornblende diorite containing brown hornblende (with rare clinopyroxene cores), plagioclase, Fe-Ti oxide, and abundant sphene. Look for pegmatitic segregations and felsic veinlets containing small amounts of garnet. Also note thin (1-2 cm) shear bands consisting of fine-grained hornblende and plagioclase. Fine polygonal textures in these narrow bands suggest recrystallization during hot ductile flow. This diorite body appears to concordantly intrude amphibolite: xenoliths of amphibolite are found in outcrops of diorite beneath the bridge. Contact-metamorphosed amphibolite containing diopside + garnet + green spinel + chlorite + clinozoisite + minor calcite crops out high on the creek bank. The extent of the diorite body is difficult to map because of the strong similarities in structure and mineralogy of host and intrusive, but similar small concordant diorite bodies have been noted elsewhere in the amphibolite. A Pb/U age determination on zircon from this locality indicates an intrusive age of approximately 154 Ma, and $^{40}Ar/^{39}Ar$ incremental heating experiments give a cooling age of about 153 Ma.

Continue north on West Fork Evans Creek Road.

0.5 (25.1)—Intersection. Turn left onto Raspberry Creek Road (BLM Road 34-3-15.2) and begin the climb to Bald Mountain.

0.6 (25.7)—Intersection with BLM Road 34-3-15.3. Stay on 34-3-15.2 by bearing left.

0.9 (26.6)—Road cuts in serpentinite and associated amphibolite on the right.

0.7 (27.3)—Intersection with BLM Road 34-3-16.2. Bear right.

1.6 (28.9)—Intersection with BLM Road 34-3-17. Turn left and proceed to the top of Bald Mountain.

2.4 (31.3)—Stop 10. Top of Bald Mountain. This locality provides excellent vistas of the surrounding countryside as well as outstanding outcrops of mylonitic micaceous schist. Park at the end of the road and walk westward on the bulldozed track another hundred feet or so along the crest of the ridge. Then turn northward and descend a short distance down the steep, grassy, north-facing slope to find the outcrops. Quartz-plagioclase-biotite schist here displays typical mylonitic textures: reduction in grain size, enhanced lineation defined by elongated quartz grains, flattened and elongated feldspar grains, and strong foliation. The lineation plunges gently to the southeast. Look in faces parallel to the lineation (the XZ plane of the strain ellipsoid) to find rotated feldspar porphyroclasts that might indicate sense of shear. Thin-section and quartz petrofabric work demonstrates top-to-the-northwest sense of shear, but this may be difficult to see in outcrop. Also note isoclinal folds that deform foliation.

Turn around and begin descending.

2.5 (33.8)—Intersection with Raspberry Creek Road. Instead of turning right (the way you came), continue straight on Road 34-3-17.

0.7 (34.5)—Quarry in serpentinite. Strongly sheared serpentinite consists mainly of antigorite. This is one of many small serpentinite bodies present near and within the contact zone between the May Creek Schist and the amphibolite. Road cuts just west of the quarry entrance are amphibolite and for the next mile or so alternate between metasedimentary rocks and amphibolite.

0.9 (35.4)—Intersection with May Creek Road (BLM Road 35-3-5). Turn left.

0.5 (35.9)—Road cuts in ultramafic schist and folded amphibolite.

2.5 (38.4)—Confluence of Fawn and May Creeks. A fire devastated this area in 1987 and temporarily made it easier for geologists to see outcrops of the May Creek Schist at its type locality (but watch out for poison oak). Outcrops in the creek consist of monotonous, gray, lineated micaceous quartzite.

0.3 (38.7)—Fawn Creek Road.

1.1 (39.8)—Intersection with Evans Creek Road. Turn right.

1.9 (41.7)—Borrow pit in lineated and foliated rocks of the May Creek Schist on right.

0.3 (42.0)—Road cuts in the May Creek Schist on right.

0.7 (42.7)—Sykes Creek Road.

1.6 (44.3)—Entering town of Wimer. Turn left to cross Wimer Covered Bridge.

0.9 (45.2)—Intersection of Covered Bridge Road with Pleasant Creek Road. Turn left.

3.4 (48.6)—Borrow pit in weathered dioritic rocks of the Wimer pluton.

3.6 (52.2)—Entering town of Rogue River. **End of road log.**

Part 3 (Day 2) of this field trip has been discussed and published elsewhere: See Harper (1989) in references for part 1 on page 32 of this issue. □

TIC invites sponsorship of geologic markers

The Travel Information Council (TIC) is responsible through its historical marker program for commemorating significant events in Oregon. Over 80 sites important to the state's past—from those dealing with glaciation occurring many years ago to the Tillamook Burn from the 1930s—are the subjects of markers. The Department of Geology and Mineral Industries has plans to place at least one new marker per year to highlight and explain the spectacular geologic offerings in Oregon.

The historical marker program began in 1939 and was administered by the Oregon Department of Transportation until July 1991, when it was adopted by TIC. Reactivating a program that was dormant for over 20 years, TIC will refurbish the existing markers and erect new markers throughout the state.

Wallowa Lake marker near Joseph.

A state agency that deals with motorist services, TIC encourages the participation of sponsoring groups in the marker program. New marker application forms ask sponsoring groups to identify the significance of the event, person, or place to be commemorated and to suggest a possible location. Approval of the subject is followed by text and marker design and finally by the manufacture and placement of the marker. In financing the marker, TIC covers 75 percent of the cost; 25 percent is the responsibility of the sponsoring group. Applications can be obtained from the Travel Information Council, 229 Madrona Avenue S., Salem, OR 97302. *—TIC news release*

Capitol mineral display shows new collection

The Clackamette Mineral and Gem Corporation of Oregon City has provided the new exhibit in the display case of the Oregon Council of Rock and Mineral Clubs (OCRMC) at the State Capitol in Salem. It is the first display presented by this club.

Club members Bernie and Winnie Schulz and Jack and Pat Jordan arranged the exhibit on the glass shelves of the 11-ft-long, lighted case. The variety of materials to be found in Oregon is the main theme of the display that shows treasures from 18 Oregon counties, including Thundereggs, Oregon's state rock, and Oregon sunstone, the state gemstone. The collection also presents petrified wood, coral, Tempskya fern, and vertebrae; white and Cedar Mountain jade; rhodonite; jasper from Hart Mountain, Owyhee, and Biggs locations; pink and green limb casts from Crook County; obsidian in slab and sphere forms; Graveyard Point and Eagle Rock plume agate; sagenite; and Holley blue agate from Linn County.

The top shelf features a gem tree made of Oregon sunstones, along with faceted and colored sunstones and two faceted-sunstone necklaces. The shelf below shows a gem tree of Holley blue agate and two framed pictures made with Holley blue agate chips.

The OCRMC display case is located on the main floor of the Capitol building in Salem, in a hall to the west of the information desk. Since it was first installed in 1982, it has held displays by many different Oregon rock clubs. Generally, three displays per year are presented. The new display is scheduled to remain in place until May 15, 1992. *—OCRMC news release*

How geologists tell time—Part 2: Absolute dating techniques

by Evelyn M. VandenDolder, Editor, Arizona Geological Survey.

The following article was originally published as a two-part article in the winter 1990 and spring 1991 issues (v. 20, no. 4; v. 21, no. 1) of *Arizona Geology*, published by the Arizona Geological Survey, 845 N. Park Avenue, Suite 100, Tucson, AZ 85719. With the publisher's permission, Part 1 was reprinted in the November 1991 issue (v. 53, no. 6) of *Oregon Geology*, and Part 2 is reprinted here. In a few cases, the original illustrations had to be replaced with other, similar illustrations. *—Editors*

INTRODUCTION

Geologic time, a revolutionary concept that has taken several centuries to develop, may be measured by both relative and absolute dating techniques. The former were discussed in Part 1 of this article. Nature records earthly time by two absolute methods: astronomically through tree rings, growth rings, and varve sequences, which reflect the rotation and revolution of the Earth in seasonal changes; and atomically through radioactive decay. These two standards of measurement are discussed below.

TREE RINGS

Tree rings are the most familiar seasonal records preserved in living organisms. The width and density of the rings depend on the temperature and the amount of light and moisture present when the plant cells were formed. During the spring and summer growing season, new layers of cells are produced underneath the bark of the tree. Seasonal variations are evident in early or "spring" wood, which consists of large, thin-walled cells, and late or "summer" wood, which consists of smaller cells with thicker walls. One annual ring includes one layer each of spring and summer wood (Figure 1).

Dendrochronology, the study of tree rings, has been used to date archaelogical sites, especially in the arid Southwest, where wooden beams that supported ancient dwellings are well preserved. In living trees, the outer ring was formed during the current year. By counting the total number of rings, scientists can establish an age for the living tree (Figure 2). Because living trees in the same area share a common environment, their rings exhibit a similar pattern of wide and narrow bands, which usually reflect when rainfall was plentiful or scarce, respectively. If the inner-ring pattern of a living tree matches the outer-ring pattern of an ancient tree (e.g., a structural beam of an old building) that grew in the same area, the rings were formed during the same time and, thus, are the same age. Through such cross-dating, dendrochronologists can determine when the ancient tree was cut and the edifice built.

In the Southwest, the continuous tree-ring chronology extends back to 322 B.C. By piecing together tree-ring data from various parts of the world, scientists have extended the continuous chronology even further to 7938 B.C. (Stuiver, 1990). Bristlecone pines in the western United States and oaks in Irish peat bogs are among the trees used to establish this chronology.

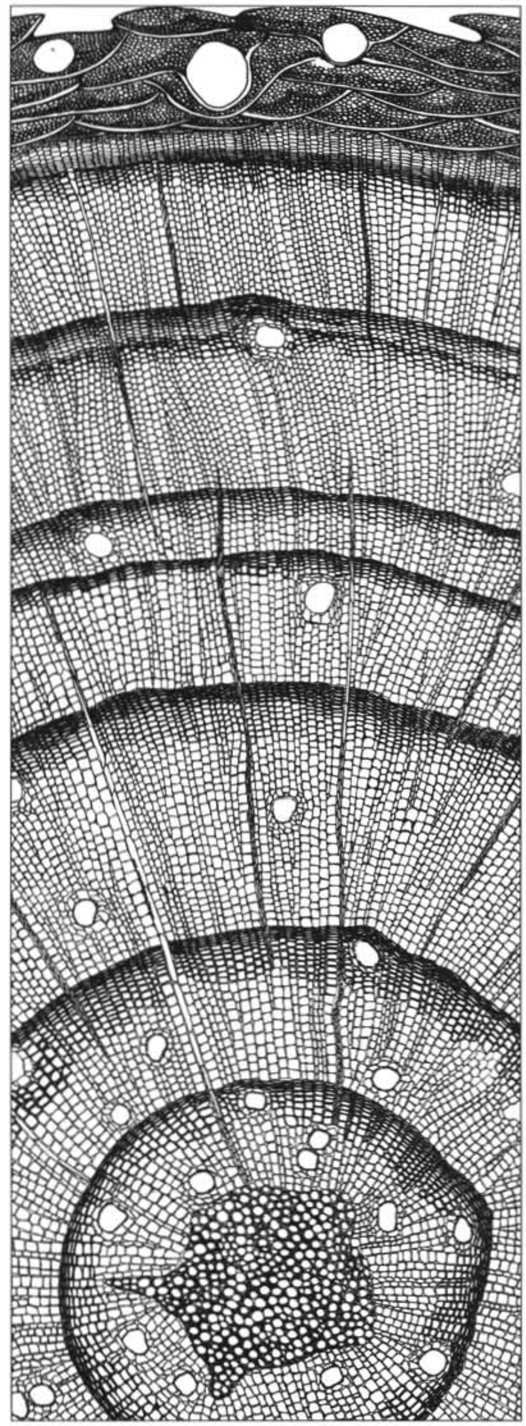


Figure 1 (right). Generalized illustration of the cross-section anatomy of conifers. Note the differences between early or "spring" wood (with large, thin, light-colored cells) and late or "summer" wood (with small, thick, dark-colored cells). New tree rings are produced by the cambrium, a layer of undifferentiated plant cells directly underneath the bark. The large, open circular areas are resin ducts, which are intercellular spaces lined with thin-walled cells that secrete resin into the duct. Resin protects the plant from attack by decay-producing fungi and bark beetles. Drawing by Terah L. Smiley. Copyright 1947 by Laboratory of Tree-Ring Research, University of Arizona. Reprinted with permission.

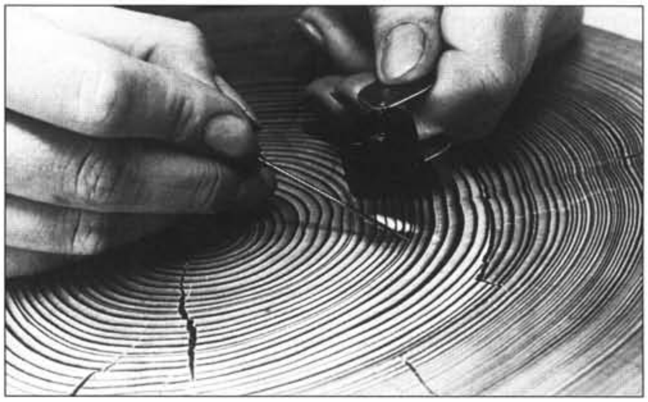


Figure 2. Dendrochronologist examines a cross section of a Douglas fir tree from an archaeological site. Copyright 1984 by Laboratory of Tree-Ring Research, University of Arizona. Reprinted with permission.

GROWTH RINGS

Some aquatic organisms also record seasonal variations in temperature and food supply, especially those that live in lakes in the Temperate Zone where temperature fluctuations are extreme. Freshwater clams typically grow annual bands that resemble tree rings. Dark, narrow bands indicate colder weather, when scarce food restricted shell growth. Lighter and wider bands indicate a warmer season and more abundant food supply (Stokes, 1966). These rings are also evident in fossil shells.

Fish scales, both modern and fossilized, show tiny annual growth rings called "annuli." Corals, on the other hand, record daily growth rings. By studying the rings of fossil corals from the Devonian Period (about 375 million years [m.y.] ago), geologists concluded that there were 400 days in a year and inferred that days were shorter during this time (Stokes, 1966).

VARVE SEQUENCES

Seasonal changes are also reflected in the sedimentary record. Precipitational variations during the wet and dry seasons locally affect erosion, transportation, and deposition of sediments. Wet seasons with high stream flow cause rapid deposition of sediments, whereas dry seasons with low flows cause little or no deposition.

A **varve** is a sedimentary layer deposited in a body of still water, such as a lake, within a single year. The term "varve" specifically refers to an annual layer deposited in a glacial lake by meltwater streams. A glacial varve includes two layers: a lower "summer" layer composed of coarse-grained, light-colored sediments, such as sand or silt, and formed by rapid melting of ice and vigorous runoff during the warmer months; and an upper, thinner "winter" layer composed of very fine grained, often organic, darker clay sediments and produced when suspended particles were slowly deposited while the streams were icebound and the lakes quiet. Glacial varves range from less than an inch to several inches in thickness (Figure 3; Stokes, 1966).

Hundreds of years have been recorded within the varves of a single lake or pond (Stokes, 1966). Variations in the size of varves, due to differences in the length and warmth of seasons, allow geologists to correlate varve sequences. The oldest preserved sequence associated with a particular glacier generally lies adjacent to the area where that glacier reached its maximum extent. The youngest sequence is nearest the glacier's edge (if the glacier still exists) or lies where an "extinct" glacier retreated and melted away. Geologists have counted and correlated varves to determine the ages of Pleistocene glacial deposits and the time when the last ice sheets retreated from Europe and North America.

Figure 3. Middle Pleistocene varves of the Hayden Creek glaciation (approximately 140,000 years B.P.) along Canyon Creek, southeast of the Yale Reservoir, south of Mount St. Helens, Washington. Photo courtesy of Patrick Pringle, Washington Division of Geology and Earth Resources.

RADIOACTIVE DECAY

The nucleus of an atom contains two kinds of particles, each with a mass of 1 (in atomic mass units): **neutrons**, which are electrically neutral, and **protons**, each of which has an electrical charge of +1. The atomic number is equal to the number of protons, which uniquely defines an element and establishes its place among the 103 known elements on the periodic table of the chemical elements. The number of protons is also equal to the number of electrons that surround the nucleus in nonionized atoms. An **electron** has an electrical charge of −1. Because the mass of an electron is negligible, an element's atomic weight essentially equals the total number of protons and neutrons in its nucleus.

Each element consists of several **isotopes**—a word derived from a Greek term meaning "same place" (Faure, 1977). Isotopes have the same number of protons (and thus occupy the "same place" on the periodic table) but different numbers of neutrons (and thus different atomic masses and weights).

Some isotopes of every chemical element are unstable and spontaneously disintegrate to form atoms of different elements, releasing energy in the process. Isotopes radioactively decay through one of three nuclear processes: by emitting **alpha particles**, which are essentially helium nuclei composed of two protons and two neutrons; by emitting **beta particles**, or high-energy electrons; or by capturing electrons. An element that emits an alpha particle becomes another element because it loses two protons. The electrons that are beta particles are not released from the electron cloud surrounding the nucleus but from the nucleus itself.

A neutron breaks up, emits an electron, and becomes a proton, thus creating a new element with one more proton and one less neutron than the previous element. In **electron capture**, a proton in the nucleus picks up an orbital electron and turns into a neutron, thus creating a new element with one less proton and one more neutron (Faure, 1977).

The initial atoms of a radioactive isotope are called **parents**; the new atoms produced after a decay are called **daughters**. One daughter atom is produced by the decay of one parent atom; thus, the number of daughter atoms in a rock or mineral is equal to the number of parent atoms that decayed, as long as no daughter atoms leaked from the sample. Radiometric dating based on the disintegration of parent atoms into daughter atoms may be roughly compared to an hour glass, which tells time by the amount of sand that flows from one chamber to another. By determining the ratio of daughter atoms to parent atoms still in the sample, scientists can determine the original amount of parent atoms in the rock or mineral. For other isotopes, this date represents the time when a mineral cooled to its **blocking temperature**. When the temperature of a mineral is above its blocking temperature, parent or daughter atoms can leak from the sample, thus resetting the radiometric clock or preventing it from even starting. The blocking temperature is specific to the type of mineral. Some geologists study the cooling histories of rocks by determining the radiometric ages of various minerals for which the blocking temperatures are known. This type of research is called **thermochronology**.

The nuclear reactions within radioactive isotopes (also called **radioisotopes**) occur almost instantaneously. Although it is impossible to predict when atoms will disintegrate, scientists have determined how long it takes for a specific quantity of atoms to decay. This rate of decay is determined by the number of atoms (n) that disintegrate in a specific period of time, usually per second or per year, relative to the total number of atoms (N) of that isotope in any given amount of material. The ratio n/N, called the **decay or disintegration constant**, is invariable no matter what N is (Press and Siever, 1982). In other words, the rate of decay is fixed for a given isotope.

Rates of decay, which have been experimentally determined for most radioisotopes, are defined in terms of half-lives. The **half-life** of an isotope is the time required for half of the original number of atoms (parents) to decay. The remaining parent atoms disintegrate at the same rate, being diminished by half during each half-life period until their number approaches zero. [Thus, from one half-life period to the next, the decay proceeds exponentially, e.g., 1—½—¼—⅛, etc., whereas a linear process would appear as 1—½—0. (Illustration of original text not reprinted. -Ed.)] Half-lives range from a fraction of a second in some isotopes to billions of years in others. ^{14}C (pronounced "carbon 14"), a radioisotope of carbon, for example, has a half-life of 5,730 years, whereas ^{87}Rb, a radioisotope of rubidium, has a half-life of 50 billion years (b.y.). The half-life of a radioisotope determines the number of years, and thus the types of rocks or minerals, that it might effectively date. A sophisticated ^{14}C-counting instrument at the University of Arizona in Tucson uses this radioisotope to date objects up to 60,000 years old, or about 10.5 half-lives, at which point only $1/_{1,448}$ of the original amount of ^{14}C remains in the sample (P.E. Damon, oral communication, 1991). ^{87}Rb, in contrast, may be used to date the oldest rocks on Earth, which are almost 4 b.y. old.

When dating rocks and minerals by radiometric methods, geologists make three major assumptions. First, the rate of decay is accurately known and constant, i.e., it does not vary with changes in temperature or pressure. Once a quantity of a radioisotope is formed in any part of the universe, it begins releasing atoms at a definite rate. Evidence that decay rates are constant is derived from interpretations of the light spectra of stars, some of which are older than the Earth. Second, the daughter atoms are solely the product of radioactive decay of the parent. No daughter atoms were present in the rock or mineral specimen before the radiometric clock began ticking. Third, the rock or mineral being dated has remained a "closed" system. No changes have occurred, such as reheating, that have allowed daughter atoms to leak out or parent atoms to be added. Such changes would reset the radiometric clock, as would a cracked hourglass that allowed sand grains to escape. Radiometric dating actually determines the time that has elapsed since sand grains escaped from the hourglass, i.e., since the last time that the mineral within a rock sample was at a temperature above its blocking temperature (Faure, 1977).

To count the atoms of a radioisotope, scientists use a **mass spectrometer**, a machine that was developed during the 1920's and 1930's. A mass spectrometer produces a beam of electrically charged atoms from a rock or mineral sample. This beam is then deflected by electrical and magnetic fields. The atoms that compose the beam are proportionately deflected according to their atomic masses, and thus may be separated and counted. During World War II, dating techniques were developed and refined as part of the Manhattan Project, the U.S. government's effort to develop the atomic bomb (Press and Siever, 1982). The mass spectrometer has since evolved into a tool that is used to research problems in geology, chemistry, and biology, as well as physics. Scientists continue to improve the sensitivity and precision of this instrument.

Several radiometric dating techniques are used today. The most common are the K-Ar, Ar-Ar, U-Pb, Th-Pb, Rb-Sr, ^{14}C, and fission-track methods.

K-Ar and Ar-Ar methods

Potassium (K) is one of the eight most abundant elements in the Earth's crust and a major constituent of many rock-forming minerals (Faure, 1977). Because of potassium's abundance and isotopic character, the most commonly used radiometric technique is based on the decay of radioactive potassium (^{40}K).

^{40}K decays via one of two paths: About 89 percent of ^{40}K atoms disintegrates by beta decay to stable calcium (^{40}Ca); the remaining 11 percent disintegrates by electron capture to stable argon (^{40}Ar; Faure, 1977). The quantity of the latter is used to determine the age of the mineral because ^{40}Ar can be distinguished from atmospheric argon, whereas ^{40}Ca cannot be separated from ordinary calcium. In addition, argon can be completely liberated simply by melting the rock or mineral. The K-Ar technique, discovered in 1948 (Stokes, 1966), is used to date potassium-bearing minerals and rocks that retain radiogenic argon at low temperatures. These include biotite and muscovite (both micas) and hornblende in plutonic and metamorphic rocks, as well as feldspar in volcanic rocks. Because they are very common in igneous and metamorphic rocks, micas are the best minerals to date by this technique. The K-Ar method cannot, however, be used to date sedimentary rocks. Minerals that were transported and deposited are generally older than the sedimentary rocks that contain them, and minerals that did form at the same time as the rocks are commonly affected by **diagenesis** (the chemical, physical, and biological processes that turn sediments into rock). The half-life of ^{40}K is 1.31 b.y. Rocks from 10,000 years old to the oldest rocks on Earth may be dated by the K-Ar method (Table 1; Jones, undated).

When using this method to determine the age of crystallization, geologists assume that no argon was present in the mineral when it formed and that it has retained argon since it cooled through its argon blocking temperature (Faure, 1977). ^{40}Ar, however, is the only isotope commonly used in dating that is a gas; thus, it may easily escape from a mineral, especially at temperatures exceeding several hundred degrees centigrade (Dalrymple and Lanphere, 1969). The K-Ar date is the time at which the mineral cooled enough to prevent ^{40}Ar from escaping. This blocking or closure temperature differs with each mineral. For hornblende, for example, the ^{40}Ar blocking temperature ranges between 480 °C and 570 °C, depending on whether the rock cooled slowly (5 °C/m.y.) or quickly (1,000 °C/m.y.). For the feldspar microcline, however, the ^{40}Ar blocking temperature ranges from

Table 1. *Common radiometric dating methods. Compiled from Wyllie (1971), Faure (1977), and Jones (undated)*

Parent	Daughter	Half-life (years)	Effective dating range	Some materials that may be dated
^{40}K	^{40}Ar	1.31×10^9	10^4 years to Earth formation	Micas, hornblende, feldspar
^{235}U	^{207}Pb	7.13×10^8	10^7 years to Earth formation	Zircon, uraninite, allanite, monazite, sphene, apatite, epidote, thorite
^{238}U	^{206}Pb	4.51×10^9	10^7 years to Earth formation	Same as ^{235}U
^{232}Th	^{208}Pb	1.39×10^{10}	10^7 years to Earth formation	Same as ^{235}U
^{87}Rb	^{87}Sr	5.0×10^{10}	10^7 years to Earth formation	Potassium feldspar, micas, clay minerals
^{14}C	^{14}N	5.73×10^3	0 to 6×10^4 years	Wood, fabric, paper, rope, seeds, bone, pottery
Fission tracks from U decay			0 years to Earth formation	Apatite, micas, sphene, epidote, garnet, zircon, tektites, glass

120 °C to 180 °C (McDougall and Harrison, 1988). Though perceived as a disadvantage by some scientists, the potential for argon loss is actually considered an advantage by others because K-Ar dates are useful in determining the cooling histories of plutonic and metamorphic rocks.

A variation of the K-Ar technique has been used to overcome some of its limitations. In the Ar-Ar method, the isotopic ratios of ^{40}Ar and ^{39}Ar in the sample are determined. ^{39}Ar is produced from ^{39}K through a reaction induced by neutron irradiation of the sample in an atomic reactor. Because absolute measurements of potassium and argon concentrations are unnecessary, the Ar-Ar method is used to date very small or valuable samples, such as lunar rocks or meteorites. This technique, unlike the K-Ar method, can commonly determine if argon has been added or lost since the time of crystallization (Faure, 1977).

U-Pb and Th-Pb methods

Uranium (U) and thorium (Th) radioactivity, discovered at the turn of the century, was the first to be used in dating rocks and minerals (Faure, 1977). Because they have similar electron configurations, these two elements also have similar chemical properties and decay schemes. Two radioisotopes of uranium (^{235}U and ^{238}U) and one of thorium (^{232}Th) disintegrate to lead (Pb) through alpha and beta decay. The reactions include chains of radioactive intermediate daughters, but the parents and stable daughters are as follows: $^{235}U \rightarrow {}^{207}Pb$; $^{238}U \rightarrow {}^{206}Pb$; and $^{232}Th \rightarrow {}^{208}Pb$ (Faure, 1977).

Ordinary lead consists of four naturally occurring isotopes: ^{208}Pb, ^{207}Pb, ^{206}Pb, and ^{204}Pb. The first three are radioactive-decay products; ^{204}Pb is nonradiogenic. Any lead that was incorporated into a mineral at the time of crystallization consists of all four isotopes. Scientists assume that the total amount of ^{204}Pb has remained constant since the Earth was formed, whereas the amounts of ^{206}Pb, ^{207}Pb, and ^{208}Pb have steadily increased because of radioactive decay (Faure, 1977). The amount of ^{204}Pb is therefore used as a stable reference isotope to determine the ratios of the other lead isotopes.

Separate age calculations using the different uranium isotopes are commonly made for a single sample. Coinciding values, called **concordant ages**, represent the time of crystallization. Values that disagree, called **discordant ages**, indicate that parent or daughter atoms, most commonly lead, were gained or lost through thermal metamorphism (heating) or other processes. By examining the results of these analyses, researchers may be able to obtain both the crystallization and metamorphic ages of the mineral.

The half-lives of ^{235}U, ^{238}U, and ^{232}Th are 713 m.y., 4.5 b.y., and 13.9 b.y., respectively. Rocks from approximately 10 m.y. old to the oldest rocks on Earth may be effectively dated by these methods (Table 1). Intermediate parent-daughter sequences of the ^{235}U and ^{238}U decay series have also been used to date minerals between 50,000 and 300,000 years old (Sawkins and others, 1978). One intermediate sequence, the decay of ^{238}U to ^{234}U and ^{230}Th (the half-life of which is 75,000 years) is used to calibrate radiocarbon dates. (See section titled "^{14}C method.")

As molten magma cools and crystallizes, uranium and thorium become concentrated in the more silica-rich components. Granitic igneous rocks thus contain more uranium and thorium than does basalt (Faure, 1977). Uranium and thorium are contained in many minerals, but minerals that are rich in these elements are rare. Only minerals that retain uranium, thorium, their intermediate daughters, and lead may be effectively dated by the U-Pb and Th-Pb methods. Zircon is the best choice for these techniques; other useful minerals are uraninite (pitchblende), allanite, monazite, sphene, apatite, epidote, and thorite. Because these minerals, as well as uranium and thorium, are commonly present in more silicic rocks, this technique is commonly used to date rocks with a high SiO_2 content (Faure, 1977; Jones, undated).

Rb-Sr method

Radioactive rubidium (^{87}Rb), through release of a beta particle, disintegrates to strontium (^{87}Sr). Because the half-life of ^{87}Rb is so long (about 50 b.y.), its accuracy is somewhat uncertain. For this reason, the Rb-Sr method cannot be used to date young rocks.

The Rb-Sr technique is used to date rubidium-bearing minerals, such as micas, potassium feldspar, and clay minerals, in igneous and metamorphic rocks (Table 1). Thermal metamorphism may release daughter atoms and reset the radiometric clock in rubidium-bearing minerals. Whole-rock samples the size of hand specimens, however, may remain closed systems even if metamorphism has occurred (Faure, 1977). Rubidium and strontium may migrate from one mineral to another but remain within the rock. The Rb-Sr technique, therefore, may be used to establish the time of crystallization through whole-rock analysis, as well as the time of metamorphism through separate mineral analyses. It may be the most valuable method for dating metamorphic rocks.

^{14}C method

Radioactive carbon (^{14}C) is naturally created in the atmosphere when cosmic-ray-produced neutrons interact with stable nitrogen (^{14}N) atoms, causing each atom to lose one proton. The ^{14}C atoms are quickly oxidized to CO_2. When a plant is alive, it "breathes" in CO_2 and incorporates into its cell structure carbon molecules from the CO_2 through the process of photosynthesis. Carbon from the atmosphere includes both radioactive ^{14}C and the more abundant stable isotope ^{12}C. When a plant dies, photosynthesis and CO_2 intake both cease. As the age of the dead organic material increases, the amount of ^{14}C in that material decreases due to beta decay to ^{14}N, whereas the amount of ^{12}C does not. The $^{14}C/^{12}C$ ratio in the plant material provides a measure of the time that has elapsed since the organism died (Faure, 1977).

Unlike other radioisotopes, ^{14}C does not have to be measured by use of a mass spectrometer. Instead, the amount of ^{14}C in the sample may be indirectly determined by counting the number of beta particles emitted, which is proportional to the number of ^{14}C atoms present. This total is compared to the ^{14}C radioactivity in living plant tissues. In preparation for ^{14}C dating, the sample is treated to remove impurities and burned with oxygen or treated with acid to release CO_2 gas. This gas is also treated to remove impurities and compressed within a copper tube. ^{14}C emissions are then counted for 12 hours or more, depending on the sample's age (Faure, 1977).

During the past decade, mass spectrometry has been increasingly used instead of radioactive-decay counting to measure minute amounts of ^{14}C. This method allows researchers to count all the ^{14}C atoms in a sample (or at least those that the detector collects), not only those that decay during the counting period (Levi, 1990).

The ^{14}C method is used to date charcoal, wood, fabric, seeds, nutshells, paper, hide, rope, bone, ivory, and pottery, especially for archaeological purposes. The half-life of ^{14}C is about 5,730 years. The most sophisticated mass spectrometers can use ^{14}C to date small samples up to 45,000 years old. The most sophisticated counting instruments can date larger samples up to 60,000 years old (P.E. Damon, oral communication, 1991; Table 1).

The ^{14}C dating technique is based on two assumptions: (1) the level of ^{14}C activity is constant in both the atmosphere and biosphere; it does not vary with time, latitude, or species; and (2) the sample is a closed system; no ^{14}C was incorporated into tissues after the organism's death, and radioactivity is the sole cause of ^{14}C depletion. Researchers have shown, however, that the ^{14}C content of the atmosphere varies with the level of cosmic-ray activity, which in turn depends on latitude, solar activity, and the Earth's magnetic field. About 20,000 years ago, the ^{14}C content of the atmosphere was 40 percent higher than it is today (Levi, 1990). This variation is mainly due to changes in the Earth's magnetic dipole, which 30,00 years ago was only about half its current strength (Levi, 1990). The weaker field allowed more cosmic rays to penetrate the atmosphere at the mid-latitudes and thus generate more ^{14}C.

Variations in atmospheric ^{14}C levels due to human activities have also been noted. ^{14}C levels decreased from the 19th to the 20th century, possibly because of the combustion of fossil fuels during the Industrial Revolution, which added "dead" ^{14}C-depleted CO_2 to the atmosphere. They have risen, however, since 1945 because of the development of the atomic bomb, nuclear reactors, and particle accelerators (Faure, 1977). In addition to fluctuating levels of atmospheric ^{14}C, ^{14}C from surrounding water, soil, rock, or vegetation may contaminate a sample.

Because these variations may affect the accuracy of radiocarbon dates, studies of tree rings and varve sequences are commonly used to check and correct ^{14}C dates of sample materials. By measuring the ^{14}C content of annual rings in bristlecone pines and other trees and of varved sediments that contain organic matter, researchers can determine the ^{14}C content of the atmosphere at the time the rings and varves were formed. Radiocarbon dates that are cross-checked with dates from tree rings or varve sequences are exceptionally accurate. These calibrations, however, cover only about the last 9,000 years of Earth history (Levi, 1990).

By comparing ^{14}C and $^{230}Th/^{234}U$ ages of submerged Barbados corals researchers have recently shown that radiocarbon dates of 20,000 years could be as much as 3,800 years too young (Bard and others, 1990; Stuiver, 1990). Because the $^{230}Th/^{234}U$ dates were determined by a high-precision mass-spectrometry technique, the researchers were able to calibrate ^{14}C dates up to 40,000 years ago (Levi, 1990). The adjusted ^{14}C time scale recalibrates the dates of global glacial periods, as well as the ages of some archaeological artifacts. Scientists will continue to refine radiocarbon dating techniques and use other methods to cross-check ^{14}C dates.

Fission-track method

Uranium isotopes generally disintegrate by emitting an alpha particle but sometimes undergo an alternate mode of decay: spontaneous nuclear fission. The nucleus spontaneously breaks into two charged particles that travel in opposite directions, leaving trails of molecular destruction as their energy is transferred to the atoms of the mineral. If the mineral is etched with acid, the more soluble damaged areas become enlarged and are visible as tracks under an optical microscope (Figure 4). These tubular **fission tracks**, which are mostly created by the spontaneous fission of ^{238}U atoms, are 2-3 microns wide and 10-20 microns long (Gleadow and others, 1983). Scientists estimate that for every 2 million ^{238}U atoms that decay by alpha emission only one will fission (Jones, undated).

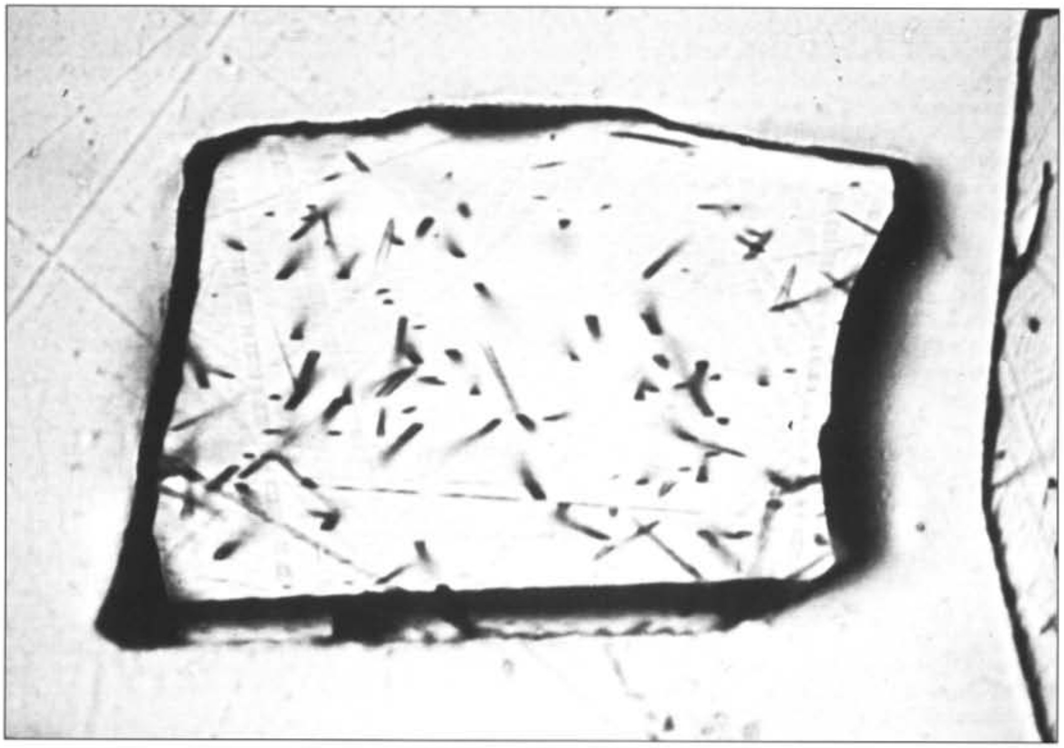
The density of fission tracks in a mineral increases with time and uranium concentration, but the tracks disappear if the mineral is heated above a specific temperature, known as the **annealing temperature**. Tracks in different minerals have different annealing temperatures. The fission-track method can thus provide information about the thermal histories of rocks. A fission-track date is the cooling age, not necessarily the crystallization age, of the mineral. If the mineral cooled rapidly and was not reheated, the date is the actual age of the mineral. The fission-track method is used to date apatite, micas, sphene, epidote, garnet, zircon, tektites, volcanic glass, and synthetic glass, including some archaeological objects (Faure, 1977). Samples from one decade old to the oldest rocks on Earth may be dated by this technique (Table 1; Jones, undated).

To date a mineral by the fission-track method, a researcher must determine both the density of fission tracks and the uranium concentration within the specimen. A fresh, unweathered surface of the mineral is cut, polished, and etched with acid. The specimen is then placed under a petrographic microscope, and the fission tracks are counted within a known area. To determine the uranium concentration of the sample, the researcher may prepare the sample in one of two ways. For minerals, such as apatite, in which the uranium content is homogeneous, i.e., the same in each grain, the spontaneous fission tracks are annealed, or destroyed by heating, after they are counted. The researcher then cuts, polishes, and etches a new surface of the mineral. To date minerals with nonhomogeneous uranium, such as zircon and sphene, the researcher does not heat or etch the mineral. Muscovite containing very little uranium is attached to the sample to serve as a track detector (Faure, 1977; Jones, undated). After preparing the sample by either method, the researcher irradiates it with thermal neutrons in a nuclear reactor to induce fission of ^{235}U atoms and counts the density of induced fission tracks. Because the ratio of ^{238}U to ^{235}U atoms is constant in nature (137.8:1; Faure, 1977), the density of induced ^{235}U fission tracks may be compared with that of spontaneous ^{238}U fission tracks to determine the number of parent atoms that were originally in the sample.

Fission-track dating has several advantages. This analysis does not require the use of a mass spectrometer and is relatively easy to perform. It may be used to date materials, such as highly weathered rocks and minerals, that cannot be dated by other means. Disadvantages of this method, however, are that the track density of the sample must exceed 10 tracks per cm^2 and that the sample must be relatively free of inclusions and defects to permit counting (Faure, 1977).

Alpha particles emitted by radioisotopes do not release enough energy to produce fission tracks. They may, however, produce **pleochroic haloes**, minute, dark or colored concentric rings surrounding inclusions of radioactive minerals. The intensity of the ring color depends on the number of alpha emissions. Coloration increases to a maximum intensity, as the number of emissions and the age of the mineral increase, but then decreases, as radiation damage becomes extreme. Pleochroic haloes have been extensively studied in biotite, because this mineral has perfect cleavage, and the haloes are readily visible. The accuracy of the pleochroic-halo dating method, however, remains controversial (Faure, 1977).

Figure 4. Spontaneous fission tracks in apatite mineral grain, as viewed through a petrographic microscope at a magnification of 1,000X. These natural tracks (short, dark lines) were produced by the spontaneous fission of ^{238}U atoms. The very long, light-colored lines are merely scratches of the surface of the grain. This apatite is from a granodiorite from the Dry Valleys of Antarctica. The apatite fission-track age of this particular sample (58 ± 4 m.y.) reflects early Cenozoic uplift of the Transantarctic Mountains. Photo by Paul Fitzgerald, Department of Geology, Arizona State University.



Other methods

Several other techniques have been used to date certain rocks and minerals that cannot be dated by the conventional methods described above. The most promising methods are based on beta decay of the naturally occurring radioisotopes of rhenium (^{187}Re) and lutetium (^{176}Lu) to osmium (^{187}Os) and hafnium (^{176}Hf), respectively. The Re-Os method is used to date iron meteorites, molybdenite-bearing vein deposits, and rhenium-bearing copper-sulfide ores. The Lu-Hf method is used to date apatite, garnet, and monazite in igneous rocks. The naturally occurring radioisotopes of some rare-earth elements, most notably samarium (^{147}Sm) and lanthanum (^{138}La), have also been used to make age determinations (Faure, 1977). The alpha decay of samarium (^{147}Sm) to neodymium (^{143}Nd) has been used to date Precambrian rocks but is more commonly used as an isotropic tracer to study the genesis and history of the Earth's crust.

Although the radioactive decay of ^{40}K to ^{40}Ar, described above, is more widely used as a dating technique, the decay of ^{40}K to ^{40}Ca may be used to date minerals that are greatly enriched in potassium and depleted in calcium, such as micas in pegmatite and sylvite in evaporite rocks (Faure, 1977). The high natural abundance of ^{40}Ca, however, does pose problems with this method.

Tritium (^{3}H), a radioisotope of hydrogen, is created in the atmosphere from ^{14}N in a way similar to ^{14}C production but in smaller amounts. It is also produced by manmade nuclear explosions. Tritium, which decays to stable Helium (^{3}He), has a short half-life of about 12.5 years (Stokes, 1966; Faure, 1977). It is therefore not used to date geologic events but may be used to determine the flow rate of ground water and the circulation rate of deep ocean currents.

THE IMPORTANCE OF DATING ROCKS AND MINERALS

By dating rocks and minerals, geologists can clarify the chronology of geologic events, relationships between rock units, sources of rock materials, and timing of metamorphic and mineralizing events. Age determinations are so important to geologists deciphering the geologic history of Arizona that more than 1,600 radiometric dates had been determined for rocks in the state by 1986 (Reynolds and others, 1986). Because this history is extremely complex, geologists continue to generate dozens of new radiometric dates each year. Relative dating methods, such as those based on sedimentary sequences, fossils, and cross-cutting relationships, as well as other absolute dating methods, such as those based on tree rings, are no less valuable to geologists. These techniques provide geologic information and insights that radiometric dates cannot offer. They are also crucial to understanding the relationship between radiometric dates and the geologic history of an area. Some examples of the knowledge gained by geochronologic studies in Arizona are given below.

Such studies in western Arizona have helped in understanding the geologic history of the Gulf of California region. The Bouse Formation along the Colorado River consists of estuarine deposits, or sediments deposited in the brackish water of an **estuary**, an arm of the sea at the lower end of a river. Fossils and volcanic tuffs associated with this formation indicate that it is early Pliocene to late Miocene in age. This age and the composition of the formation suggest that the Gulf of California and the Salton Trough were connected 3-11 m.y. ago (Schmidt, 1990).

By dating minerals within a mountain range, geologists can determine not only when the rocks were formed and uplifted but also the rate of the orogenic (mountain-building) process. Rocks in the forerange of the Santa Catalina Mountains near Tucson and in the South Mountains near Phoenix were once thought to be Precambrian, or approximately 1.6 b.y. old. Because of new age determinations, it is now known that the rocks were formed during the Tertiary period. Uplift of these mountains, which was relatively fast (in geologic terms), largely occurred between 30 and 15 m.y. ago.

The mountains in the Basin and Range Province of Arizona are mostly composed of igneous and metamorphic rocks. Many of the granites in these ranges are very similar in appearance and could not be distinguished from each other without knowledge of their ages. By using radioisotopes, geologists can link ore deposits with specific intrusive episodes and formations. Except in the Bisbee area, all porphyry copper deposits in Arizona are associated with granites of a specific age (early Tertiary to Late Cretaceous, or 55-75 m.y. old). Some minerals, such as micas, were formed by the mineralizing process and therefore may be used to date the deposits. By dating micas at the Vulture mine, geologists from the Arizona Geological

Survey (AZGS) and U.S. Geological Survey (USGS) have determined that this deposit is Cretaceous, not Precambrian, as was previously thought (Spencer and others, 1989). Knowing the age of a mineral deposit is important to explorationists who are searching for more deposits of the same type.

Geothermal energy (useful energy that can be harnessed from naturally occurring steam and hot water, such as hot springs, fumaroles, and geysers) is associated with areas of Quaternary volcanic activity. Volcanic rocks in western Arizona were once thought to be Quaternary (less than 1.6 m.y. old) or Cretaceous (66-144 m.y. old). If they had been Quaternary, they would have been prime sites for geothermal energy, and thus they were the subject of several geothermal studies. If they had been Cretaceous, they would have been prime sites for porphyry copper deposits. Because of recent geologic mapping and age determinations by geologists from the AZGS, USGS, and University of Arizona, it is now known that these rocks are middle Tertiary (20-40 m.y. old). Geologists can now link these rocks with other mid-Tertiary volcanic rocks (and hence other episodes of volcanism) in southern Arizona, such as those in the Chiricahua and Superstition Mountains.

By dating Quaternary materials, such as terrace (flood-plain) deposits and sediments that are cut by or overlap faults, geologists can determine the potential for flooding, earthquakes, and other geologic hazards in an area. AZGS geologists have also dated terrace deposits and studied the pattern of erosion along stream channels in the Tucson area. They have established when the last flood occurred and estimated the potential for future floods in the metropolitan area.

As the population of Arizona continues to grow, along with the demand for mineral resources and responsible city planning, the need for reliable geologic mapping, including accurate age determinations of rock units, will become increasingly important.

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Mabey earns doctoral degree

Matthew A. Mabey, who joined the Oregon Department of Geology and Mineral Industries (DOGAMI) in December 1990 as Earthquake Engineer, successfully completed the oral defense of his dissertation and has earned the degree of Doctor of Philosophy in Civil Engineering from Brigham Young University. The subject of his dissertation research was the assessment of liquefaction as an earthquake hazard, and the title of his dissertation is "Prediction of displacements due to liquefaction-induced lateral spreads."

Mabey earned two undergraduate degrees (B.S. in geology and B.S. in geophysics, 1981) at the University of Utah and a Master of Science degree in civil engineering (1989) at Brigham Young University. In addition to his work with DOGAMI, he teaches classes on earthquake hazards at Portland State University. □

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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*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

Cover photo

Mining by Glenbrook Nickel Company near Riddle in Douglas County: Contract miners are removing laterite (nickel ore) from Nickel Mountain for the Glenbrook smelter. The mine's production nearly doubled in 1992 over 1991 and provided the largest share of the growth of mineral production in 1992. See related summary report beginning on page 57.

OIL AND GAS NEWS

Mist gas wells sold

Nahama and Weagant Energy, Bakersfield, California, in partnership with Oregon Natural Gas Development Company, Portland, Oregon, have puchased 23 wells at the Mist Gas Field in Columbia County from ARCO Oil and Gas Company. This purchase includes natural gas producing wells, water-disposal and shut-in or suspended gas wells, as well as undeveloped leaseholds in the field. Nahama and Weagant Energy is now the operator of all gas wells at Mist Gas Field. The other operator present at this time, Northwest Natural Gas Company, operates the Mist Natural Gas Storage Project.

Mist Gas Field Report revised

The Mist Gas Field Report has been revised and is now available with all 1991 activity and changes shown, indicating operator, well name, location, depth, and status of all wells.

Accompanying the map is a report for all gas producers at the field since it was discovered in 1979. The report contains monthly production and revenue figures pressures, annual and cumulative production, and other data.

The Mist Gas Field Report, Open-File Report O-92-1, is now available at the publication outlet of the Oregon Department of Geology and Mineral Industries: The Nature of Oregon Information Center, Suite 177 in the State Office Building, Portland, phone (503) 731-4444. The price is $8. See further ordering instructions on the last page of this issue.□

MLR office moves

The change is so small that you may not have noticed it yet: The office of the Mined Land Reclamation Program of the Oregon Department of Geology and Mineral Industries (DOGAMI) has moved—just down the street—which changed the number in its street address: **1536** Queen Avenue SE, Albany, OR 97321. The phone number remains unchanged. (See also the listing on the left side of this page.) □

Vancouver USGS phone changes

For an update on the conditions at Mount St. Helens you will have to call a new number: A recorded message that is updated regularly can be reached now by calling **(206) 750-5057**. This service is provided by the USDA Forest Service for Gifford Pinchot National Forest and by the U.S. Geological Survey Cascades Volcano Observatory—both in Vancouver, Washington.

Please note that the message at this number gives you **geologic** information. For any other information, visitors to the volcano area are advised to call the following USDA Forest Service numbers and ask for assistance from a public affairs officer: Vancouver office of the Supervisor for Gifford Pinchot National Forest, (206) 750-5000; Mount St. Helens National Volcanic Monument Headquarters in Amboy, Washington, (206) 247-5473, or Visitors Center, (206) 247-6644.

Incidentally, Forest Service plans for the Volcanic Monument include the addition of visitors centers at Coldwater Ridge in 1993 and at Johnston Ridge in 1995—places from which the visitor will have a direct view into the crater. □

Correction

In the last issue of *Oregon Geology* (v. 54, no. 2, March 1992), the photo credit for the picture of Cow Creek Gorge (page 33) should have been to Jim **Hunt** of the USDA Forest Service. We apologize to him and to our readers for this error.

Shear wave velocity measurements in the Willamette Valley and the Portland Basin, Oregon

by Matthew A. Mabey and Ian P. Madin, Oregon Department of Geology and Mineral Industries

ABSTRACT

For the purpose of mapping the hazard represented by amplification of earthquake ground shaking by the sediment column, the Oregon Department of Geology and Mineral Industries (DOGAMI) has begun measuring shear wave velocities in the Willamette Valley and Portland Basin. These measurements are made by recording the time it takes a shear wave generated at the surface to reach a geophone located in a borehole. The shear wave velocity of unconsolidated sediments will be used to model how the sediments will respond to earthquake ground shaking.

INTRODUCTION

In order to fulfill its obligation to assess earthquake hazards in the state of Oregon, DOGAMI is developing hazard maps of areas in the state. The initial efforts are focused on the population centers in the Willamette Valley and Portland Basin. One hazard that is being mapped is the potential for amplification of ground shaking by the sediment column at a given site. A critical parameter for assessing the amount of amplification that takes place is the shear modulus of the soil. The shear wave velocity is one way to measure the shear modulus of a soil. The measurement of the travel time for shear waves generated at the surface down to a geophone located in a borehole gives a direct measurement of both average and interval shear wave velocities in the sediments between the source and receiver. These measurements have been made at seven sites so far. The shear wave velocity can then be used to develop a dynamic model of how the sediment column responds to ground shaking.

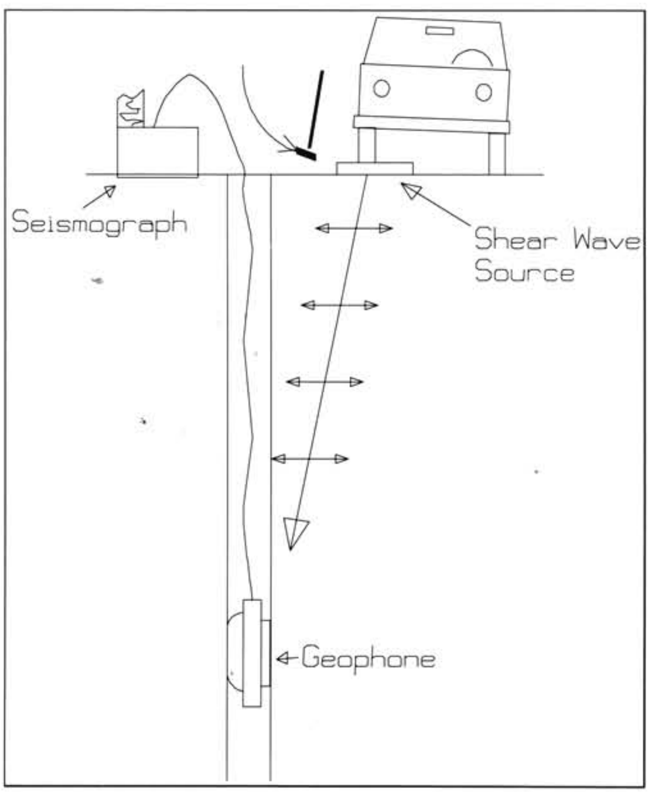


Figure 1. Diagram representing the procedure for collecting shear wave velocity data.

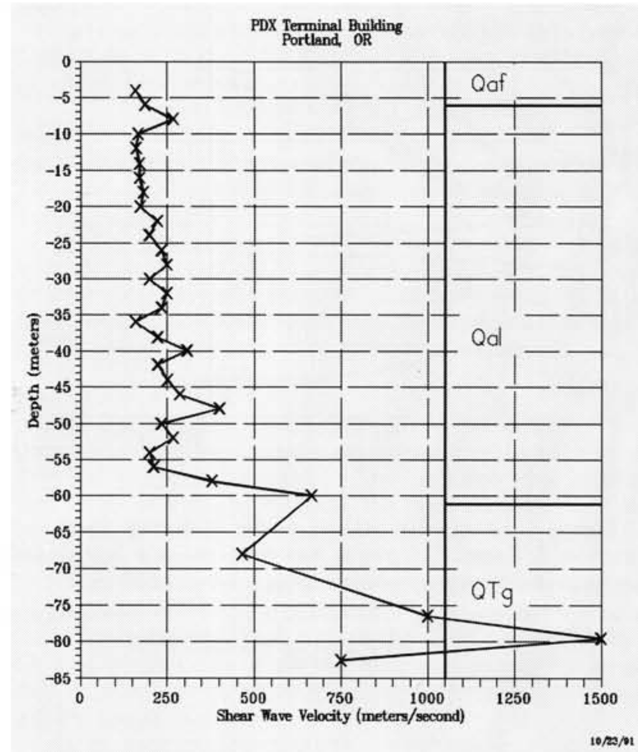


Figure 2. Shear wave velocity profile at Portland International Airport. This profile was measured in a hole immediately to the north of the main terminal building.

MEASUREMENT PROCEDURE

The shear wave velocities are measured by means of a procedure that is in common use (Stokee, 1991). The following is a brief description of some of the specifics of the implementation used for the data presented here. A Bison Series 5000 seismograph is used to record the vibrations. This seismograph is a 12-channel instrument and is equipped with digital filters. It is also a signal stacking recorder so that multiple recordings of a source-receiver configuration can be summed to increase the signal-to-noise ratio. An Oyo Geospace "Borehole Pick" (down-hole geophone) is used to detect the vibrations. This geophone is a three-component instrument that records vibrations in two orthogonal horizontal directions and in the vertical direction.

The source used to generate the shear waves is a beam struck by a sledge hammer (Figure 1 depicts the logging process). The beam is laid on the ground. Parking the wheel of a truck on top of the beam holds the beam firmly in place against the ground. Originally, a wooden beam was used, but the wood was found to deteriorate too rapidly under repeated hammer blows. The system being used now, which seems to perform very well and is very durable, is a 4-ft length of 4-in. by 4-in. steel I-beam with a 1-in. steel plate welded to one end. When the sledge hammer is hit against the end of the horizontal beam, vibrations that are predominantly horizontal shear waves are transmitted into the ground. The beam is placed 3 m horizontally away from the borehole to avoid generating tube waves in the borehole.

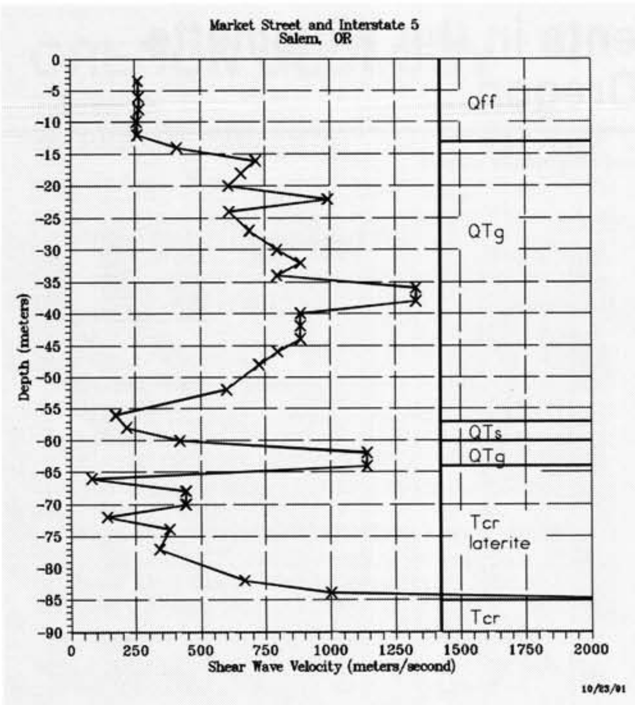


Figure 3. Shear wave velocity profile at Market Street and Interstate 5, Salem. This profile was measured in a hole drilled northeast of the overpass where Interstate 5 crosses Market Street.

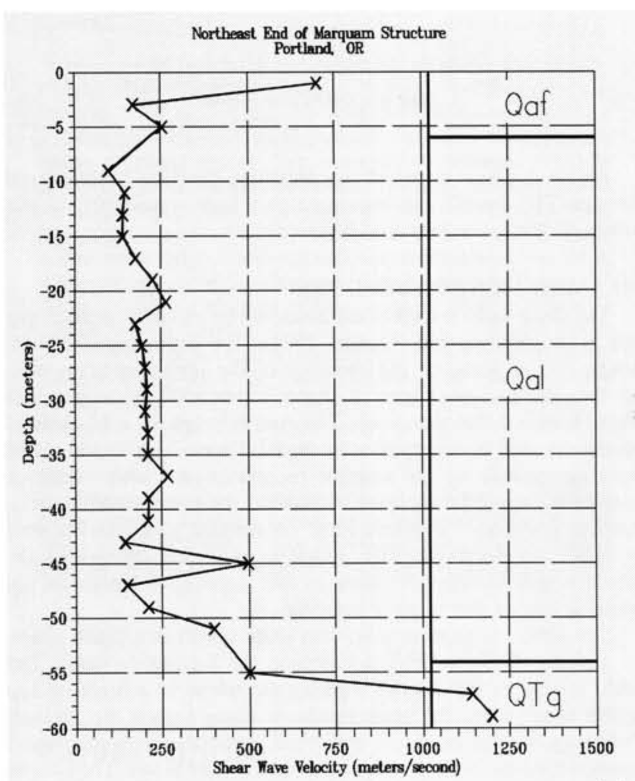


Figure 4. Shear wave velocity profile at the northeast end of the Marquam Bridge structure, Portland. This profile was measured in a hole drilled between the railroad tracks and Interstate 5, on the east side of the Willamette River, immediately north of SE Stark Street.

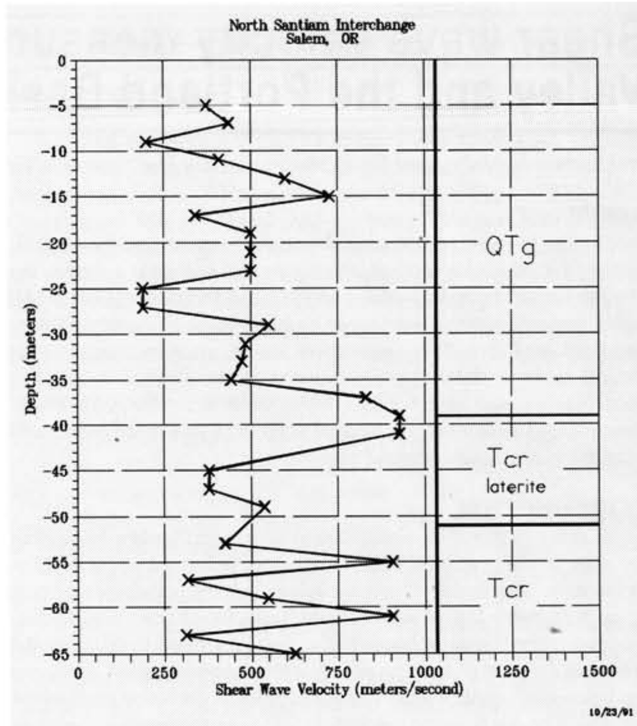


Figure 5. Shear wave velocity profile at the interchange where Interstate 5 crosses the North Santiam Highway near Salem. The profile was measured in a hole drilled to the southwest of the intersection.

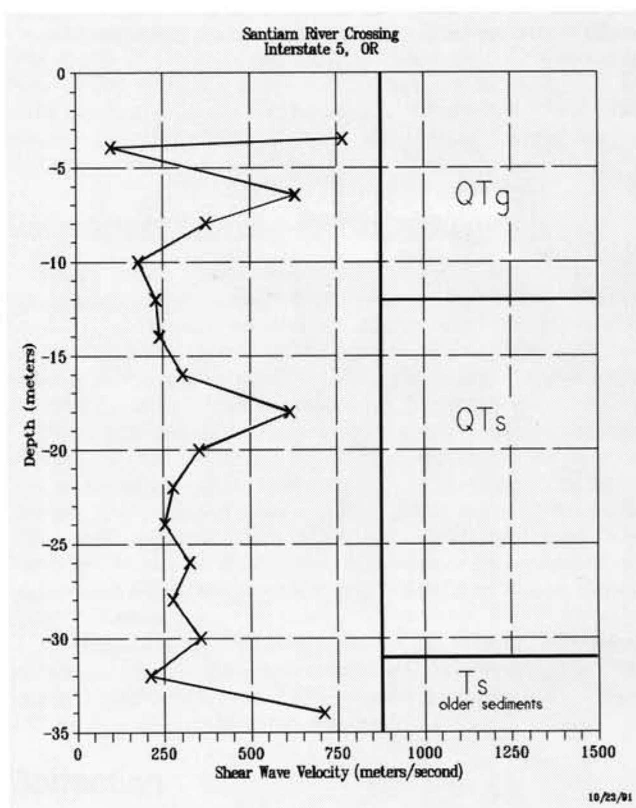


Figure 6. Shear wave velocity profile at Santiam River crossing of Interstate 5. The profile was measured in a hole drilled between the two lanes of Interstate 5, immediately south of the river.

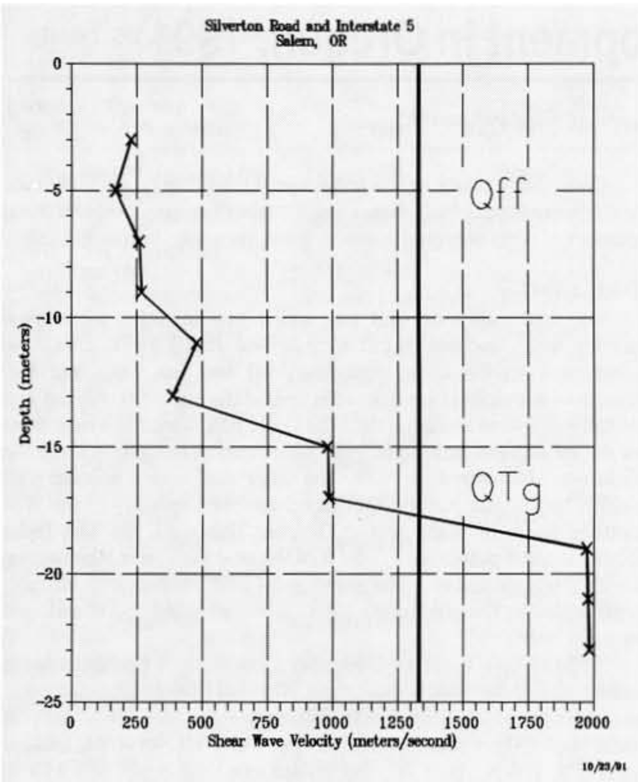


Figure 7. Shear wave velocity profile at Silverton Road and Interstate 5 in Salem. The profile was measured in a hole drilled to the southeast of the overpass where Silverton Road crosses under Interstate 5.

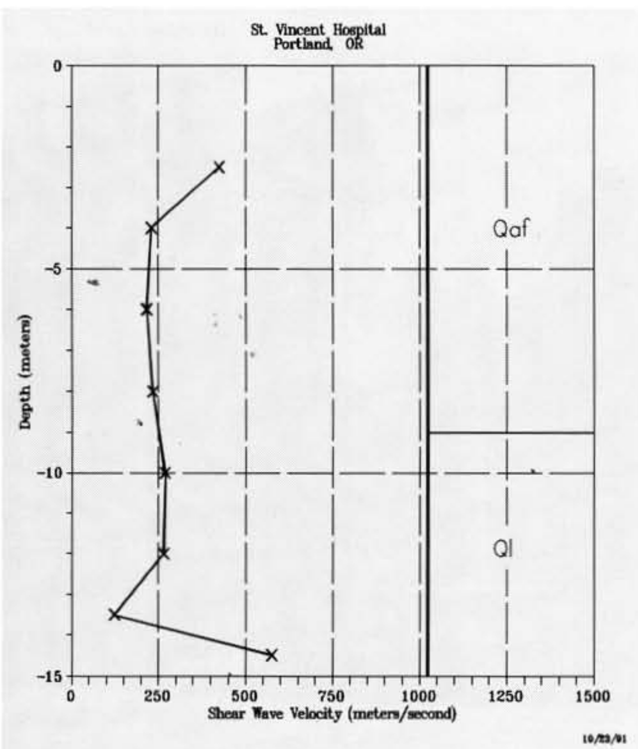


Figure 8. Shear wave velocity profile at St. Vincent Hospital, Portland. The profile was measured in a hole drilled beside the helipad that is located south of the administration building.

The generated vibrations are recorded as they arrive at the geophone, which has been lowered down a borehole. The practice has been to lower the geophone to the bottom of the hole to start. The geophone is secured in place by a pressurized rubber bladder that pushes a metal plate on one side of the geophone against the side of the borehole.

The boreholes have been completed by grouting 2- to 3-in. inside diameter PVC casing in them. The 2-in. diameter represents the smallest casing into which the geophone will fit. Casing larger than 3 in. in diameter could be logged if shims are attached to the geophone. This has not been done to date.

After a recording has been made at a given level, the pressure is released from the bladder, and the geophone is free to be raised to a higher level in the hole. Presently the recordings are being made at 2-m intervals. This process is repeated until the geophone is within 1 or 2 m of the surface.

The data recorded by the seismograph are downloaded to a laptop computer, so that they can be preserved in digital format on floppy disk. This also allows for computer-based digital processing of the data. The files are downloaded as multiplexed (intermixed in a specific pattern) time series of the three recorded channels.

DATA REDUCTION

The data that have been stored on disk are processed on a computer and yield an interval velocity profile of the soil column. The first step is to "demultiplex" the data into three separate time series or traces representing the three components of the geophone. The three recorded traces can then be displayed on a computer screen.

Arrival picks for the shear wave based on a single component of the geophone were found to be dependent on which trace was being used. Correlating waveforms from level to level was also difficult. Creating a vector sum of the two horizontal components allows extremely good correlation of the waveforms at different levels, and a single, unequivocal arrival pick is the result.

A cross-correlation function is used to aid the interpreter's choice of arrival picks and correlations of traces at different levels. The travel times are automatically corrected by the computer program for the geometric effect of the wave path varying with the depth of the measurement. An interval travel time for each 2-m logging interval is the result.

VELOCITY LOGS

Figures 2 through 8 are the results from the seven holes logged so far. These figures are plots of the measured interval shear wave velocity versus depth. Also plotted are generalized lithology logs for the holes. The lithologic units depicted correspond to the Quaternary units mapped in DOGAMI Open-File Report O-90-2 (Madin, 1990). The shear wave velocities reported here should not be viewed as a substitute for site-specific measurements. As additional shear wave velocity data are collected, the resulting profiles will be published in *Oregon Geology.*

ACKNOWLEDGMENTS

The Oregon Department of Transportation, GeoEngineers, Inc., and Rittenhouse-Zeman and Associates, Inc., provided access to the cased bore holes used to collect these data, and this indispensable assistance is gratefully acknowledged.

REFERENCES CITED

Madin, I.P., 1990, Earthquake-hazard geology maps of the Portland metropolitan area, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O-90-2, 20 p., 8 maps, scale 1:24,000.

Stokee, K.H., 1991, Application of stress waves to soil measurements: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Mo., March 11-15, Proceedings, S. Prakash, ed., v. III, Rolla, Mo., University of Missouri-Rolla, in press. □

Oil and gas exploration and development in Oregon, 1991

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

ABSTRACT

Oil and gas leasing activity declined during 1991. Four U.S. Bureau of Land Management (BLM) lease sales were held, with no leases purchased. There were no over-the-counter filings for BLM leases during the year. The total number of federal acres under lease at year's end was 230,000 acres. Three State of Oregon leases were acquired during the year. Columbia County held a lease sale at which three leases were purchased.

Five exploratory wells and one redrill were drilled at the Mist Gas Field during the year by Nahama and Weagant Energy Company, and three of them were successful gas wells. Northwest Natural Gas Company drilled two service wells at the Mist Natural Gas Storage Project. Oregon Natural Gas Development Company drilled a wildcat well in the Willamette Valley during the year; the well was plugged and abandoned.

At year's end, Mist Gas Field had sixteen gas producers and seven suspended gas wells awaiting pipeline connection. A total of 2.8 billion cubic feet (Bcf) of gas was produced during 1991 with a value of $3.9 million. DY Oil Company abandoned a depleted well during the year.

The Oregon Department of Geology and Mineral Industries (DOGAMI) revised its statutes and rules during the year, primarily those relating to application and annual fees for exploration and development wells drilled in Oregon.

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

LEASING ACTIVITY

Leasing activity declined during 1991, which is a continuation of the pattern that began during 1988. Activity included four public lease sales by the U.S. Bureau of Land Management (BLM); no bids were received at these sales. BLM received no over-the-counter filings for leases during the year. Federal leases that were terminated or that expired during 1991 totaled 240,000 acres. This includes 188,300 acres terminated for nonpayment of rentals and located primarily in eastern Oregon in Umatilla, Gilliam, Wheeler, Grant, Crook, Sherman, and Wasco Counties. The total number of federal acres under lease in Oregon at the end of 1991 amounted to approximately 230,000 acres. This includes assignments covering 159,000 acres of federal land that were approved for Hunt Oil Company and are located in Wasco, Gilliam, Jefferson, Wheeler, and Crook Counties. Total rental income during 1991 was about $310,000.

During the year, three State of Oregon leases were acquired by Nahama and Weagant Energy Company. The leases cover a total of 897 acres in Clatsop County. Leases on approximately 10,000 acres of State of Oregon lands expired or were terminated, leaving a year-end total of some 39,000 acres of State of Oregon lands under lease. The 1991 rental income was about $39,000.

Columbia County held a lease sale during 1991, at which three leases were bought by Nahama and Weagant Energy Company. Total number of acres acquired was 676 acres, for a total bonus of $1,690.

DRILLING

Six exploratory oil and gas wells, two injection-withdrawal service wells, and one redrill were drilled during 1991. This is an increase from the three exploratory oil and gas wells and two injection-withdrawal service wells drilled during 1990. All but one of the wells were drilled at the Mist Gas Field, which is where most of the oil and gas drilling activity has occurred in Oregon since the field was discovered in 1979. The other well was a wildcat well drilled by Oregon Natural Gas Development Company in the Willamette Basin of north-central Oregon. This well, the Van Dyke 32-26, located in sec. 26, T. 1 S., R. 4 W., near Gaston in Washington County, was drilled to a total depth of 3,432 ft, making it the deepest well drilled in Oregon during 1991. It was plugged and abandoned as a dry hole.

At Mist Gas Field in Columbia County, two operators were active during the year. Nahama and Weagant Energy Company was the most active, drilling five exploratory wells and one redrill. Of these wells, three were successful gas wells: CC 44-8-64, located in sec. 8, T. 6 N., R. 4 W., and drilled to a total depth of 1,810 ft; CER 14-26-64, located in sec. 26, T. 6 N., R. 4 W., and drilled to a total depth of 2,702 ft; and the redrill well CC 34-31-65 RD, located in sec. 31, T. 6 N., R. 5 W., and drilled to a total depth of 1,902 ft. The other three wells, CC 23-35-75, located in sec. 35, T. 7 N., R.

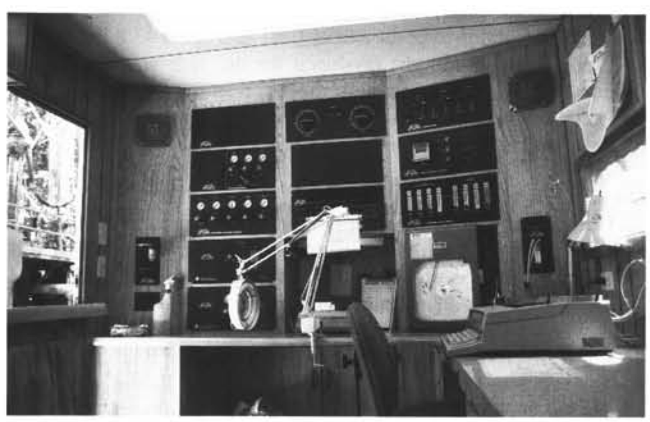
Nahama and Weagant Company drilled this well (CC 34-31-65 RD) and completed it as a successful gas producer at the Mist Gas Field during 1991. Drilling was performed by Rig 7 of Taylor Drilling Company.

Table 1. *Oil and gas permits and drilling activity in Oregon, 1991*

Permit no.	Operator, well, API number	Location	Status, depth(ft) TD=total depth PTD=proposed TD
438	Oregon Nat. Gas Dev. Van Dyke 32-26 36-067-00004	NE¼ sec. 26 T. 1 S., R. 4 W. Washington County	Abandoned, dry hole; TD: 3,432.
441	NW Natural Gas IW 13b-11 36-009-00267	SW¼ sec. 11 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 2,905.
443	NW Natural Gas IW 23d-3 36-009-00269	SW¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Completed, service well; TD: 3,079.
452	Nahama & Weagant CC 23-35-75 36-009-00278	SW¼ sec. 35 T. 7 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 3,374.
453	Nahama & Weagant CC 42-3-65 36-009-00279	NE¼ sec. 3 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,300.
454	Nahama & Weagant CC 22-2-65 36-009-00280	NW¼ sec. 22 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,000.
455	Nahama & Weagant CC 14-32-75 36-009-00281	NW¼ sec. 32 T. 7 N., R. 5 W. Columbia County	Permit issued; PTD: 3,500.
456	Nahama & Weagant Adams 31-34-65 36-009-00282	Ne¼ sec. 34 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 3,600.
457	Nahama & Weagant CC 23-31-65 36-009-00283	SW¼ sec. 31 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,340.
458	Nahama & Weagant CC 34-31-65 and RD 36-009-00284 and 36-009-00284-01	SE¼ sec. 31 T. 6 N., R. 5 W. Columbia County	Suspended, gas; TD: 2,064 and RD: 1,902.
459	Nahama & Weagant CC 44-8-64 36-009-00285	SE¼ sec. 8 T. 6 N., R. 4 W. Columbia County	Suspended, gas; TD: 1,810.
460	Nahama & Weagant LF 22-31-65 36-009-00286	NW¼ sec. 31 T. 6 N., R. 5 W. Columbia County	Abandoned, dry hole; TD: 1,991.
461	Nahama & Weagant CER 14-26-64 36-009-00287	SW¼ sec. 26 T. 6 N., R. 4 W. Columbia County	Suspended, gas; TD: 2,702.
462	Nahama & Weagant Oregon 31-36-66 36-007-00023	NE¼ sec. 36 T. 6 N., R. 6 W. Clatsop County	Permit issued; PTD: 2,430.
463	Nahama & Weagant CC 34-8-64 36-009-00288	SE¼ sec. 8 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD: 1,350.
464	Nahama & Weagant CER 12-26-64 36-009-00289	NW¼ sec. 26 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD: 2,790.
465	Nahama & Weagant CER 31-26-64 36-009-00290	NE¼ sec. 26 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD: 3,120.
466	Nahama & Weagant CC 23-19-65 36-009-00291	SW¼ sec. 19 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD: 3,000.
467	Nahama & Weagant Johnston 11-30-65 36-009-00292	NW¼ sec. 30 T. 6 N., R. 5 W. Columbia County	Permit issued; PTD: 2,700.
468	Nahama & Weagant CER 24-22-64 36-009-00293	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Permit issued; PTD: 2,600.

Drilling crew ("roughnecks") working on the drill floor at the Nahama and Weagant Energy Company well CC 22-31-65, a dry hole drilled at the Mist Gas Field during 1991.

Mud pits at the Nahama and Weagant Energy Company well CC 34-31-65. Mud pits hold the drilling mud that is pumped to the bottom of the drill hole to lift rock cuttings (produced at the bit) to the surface for examination. The drilling mud is also needed to contain the underground pressure that is exerted by the fluids in the rock formation surrounding the hole, to maintain the stability of the well, and to lubricate and cool the drill bit.



The inside of the mud loggers' trailer. Mud loggers and their trailer are present at all drill sites to examine well cuttings, monitor well conditions, and look for oil or gas shows.

Table 2. *Withdrawn permits, 1991*

Permit no.	Operator, well, API number	Location	Issue date	Reason
445	Nahama and Weagant CER 12-12-55 36-009-00271	NW¼ sec. 12 T. 5 N., R. 5 W. Columbia County	8-9-90	Application withdrawn.
448	Nahama and Weagant CER 22-16-64 36-009-00274	NW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	8-9-90	Application withdrawn.
451	Nahama and Weagant CER 14-16-64 36-009-00277	SW¼ sec. 16 T. 6 N., R. 4 W. Columbia County	10-29-90	Application withdrawn.

5 W., and drilled to a total depth of 3,374 ft; CC 34-31-65, located in sec. 31, T. 6 N., R. 5 W., and drilled to a total depth of 2,064 ft; and LF 22-31-65, located in sec. 31, T. 6 N., R. 5 W., and drilled to a total depth of 1,991 ft, were plugged and abandoned.

The second active operator was Northwest Natural Gas Company, drilling two injection-withdrawal service wells at the Mist Natural Gas Storage Project. The IW 13b-11, located in sec. 11, T. 6 N., R. 5 W., was drilled in the Bruer Pool to a total depth of 2,905 ft; and the IW 23d-3, located in sec. 3, T. 6 N., R. 5 W., was drilled in the Flora Pool to a total depth of 3,027 ft.

Total drilling footage for the year was 22,705 ft, an increase from the 12,245 ft drilled during 1990. The average depth per well was 2,523 ft, an increase from the 2,416 ft per well drilled during 1990.

During 1990, DOGAMI issued 17 permits to drill (Table 1), while 3 permits were withdrawn during the year (Table 2).

DY Oil plugged and abandoned the Neverstill 33-30 well, located at the Mist Gas Field in sec. 30, T. 6 N., R. 5 W. This well was drilled in 1989 and was no longer capable of economic production.

DISCOVERIES AND GAS PRODUCTION

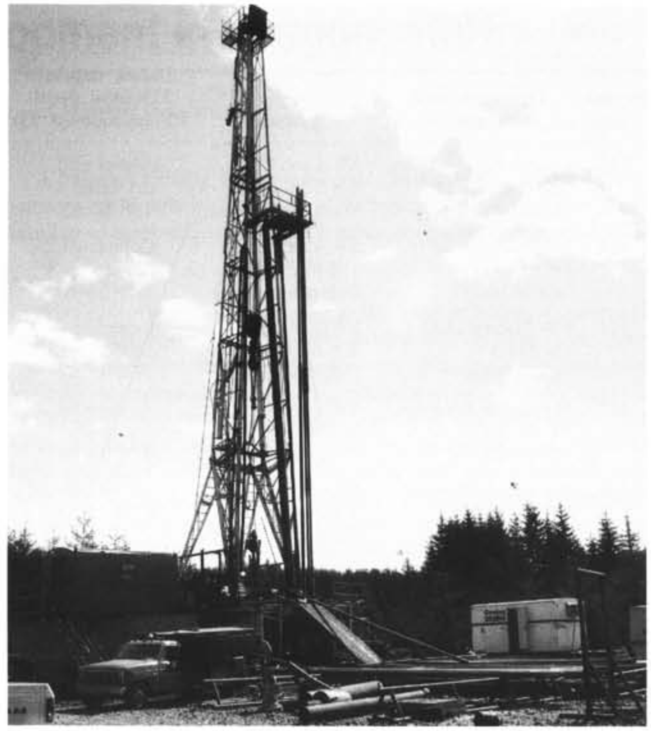
Mist Gas Field saw three new successful gas wells, an increase from the two gas wells drilled during 1990. Nahama and Weagant Energy Company is the operator of the new producers, the CC 44-8-64, CER 14-26-64, and CC 34-31-65 RD. All are located at the Mist Gas Field in Columbia County.

During 1991, twenty wells produced gas at the Mist Gas Field. At the end of the year, two companies, ARCO Oil and Gas Company and Nahama and Weagant Energy Company, were operating sixteen gas producers at the field. In addition, seven wells were suspended, awaiting pipeline connection at year's end.

Gas production for the year totaled 2.8 Bcf. This is the same amount that was produced from the field during 1990. The cumulative field production as of the end of 1991 was about 43.8 Bcf of gas. The total value of the gas produced for the year was about $3.9 million, which is approximately the same as the value of the gas produced during 1990. Gas prices ranged from around 14 cents to 15 cents per therm, which is about the same as during 1990.

GAS STORAGE

During the year, Northwest Natural Gas Company drilled two new service wells at the Mist Natural Gas Storage Project. The well IW 13b-11 is an injection-withdrawal well drilled in the Bruer Pool and the IW 23d-3 is an injection-withdrawal well drilled in the Flora Pool. The storage project now has a total of nine injection-withdrawal wells, five in the Bruer Pool and four in the Flora Pool. The pools have a combined storage capacity of 10 Bcf of gas. This allows for cycling of reservoirs between approximately 400 and 1,000 psi and will provide for an annual delivery of one million therms per day for 100 days. Gas from the Mist Natural Gas Storage Project is delivered to the Portland metropolitan area via the South Mist Feeder Pipeline.



At the Northwest Natural Gas well IW 23d-3, an injection-withdrawal well at the Flora gas storage pool, preparations are in progress to install surface casing. The surface casing consists of large-diameter pipe that is cemented in the well for protecting fresh-water resources, anchoring blowout-prevention equipment, and maintaining the integrity of the surface hole.

OTHER ACTIVITIES

Statute changes to oil and gas exploratory and development drilling laws were passed by the legislature during the year. The administrative rules relating to oil and gas exploration and development in Oregon were also revised. The major statute and rule changes relate to a change in the application fee for a permit to drill, which increased to $250 per application, a fee of $250 for a renewal of a permit, and an annual fee of $500 to be assessed on the anniversary date of each active permit. Copies of these rules (OAR 632, Division 10) are available from DOGAMI.

DOGAMI continues the study of the oil and gas potential of the Tyee Basin, located primarily in Douglas and Coos Counties in southwestern Oregon. The study, which is funded by land owners in the study area and by county, state, and federal agencies, is intended to investigate those characteristics needed to generate and trap gas and oil: source rock, stratigraphy, and structural framework. In this investigation, DOGAMI has developed and published a number of maps and reports that present a revised understanding of the geologic framework of the Tyee Basin. Additional maps and reports will be published during the current year.

During 1991, development of a transect was initiated: It will present the geology, including a geophysical cross-section, of a strip extending from a location east of the Mist Gas Field to the vicinity of Astoria and across the continental shelf and slope. This publication will be released in late spring of 1992.

The Northwest Petroleum Association (NWPA) remained active during the year. At its regular monthly meetings, speakers gave talks related to energy matters in the Pacific Northwest. For 1992, plans are to hold the annual symposium October 11-14 in Lincoln City, Oregon. The theme will be "Pacific Northwest Oil and Gas Development: Geology, Geophysics, Land, and Legal." For details, contact the NWPA, P.O. Box 6679, Portland, Oregon, 97228. □

Mining and exploration in Oregon during 1991

by Frank R. Hladky, Resident Geologist, Grants Pass Field Office, Oregon Department of Geology and Mineral Industries

ABSTRACT

Oregon's mineral industry showed an estimated 16-percent increase in value over 1990. Mineral production in 1991, including natural gas, was estimated at nearly $274 million, mostly from sand, gravel, cement, crushed stone, and nickel. The largest single growth factor was the result of the near-doubling of nickel production by Glenbrook Nickel Company. Industrial mineral industry growth was also robust, increasing at a rate of 39 percent. New metals production included Formosa Exploration, Inc., which shipped its first copper and zinc concentrate to Japan from the Silver Peak Mine in Douglas County.

The intensity of gold exploration in Oregon diminished as companies generally cut back projects, staffs, and exploration dollars, not only in Oregon, but nationwide. Two major projects nearing development remained in exploration status, as Atlas Precious Metals continued permitting activities at Grassy Mountain in Malheur County, and Plexus, Inc., continued to pursue permitting of its Bornite project in Marion County.

The Oregon Department of Geology and Mineral Industries continued mineral exploration projects in the Boise and Medford 1° by 2° sheets.

PRODUCTION HIGHLIGHTS

The value of Oregon's 1991 mineral production, excluding natural gas, was nearly $270 million, mostly from sand, gravel, cement, crushed stone, and nickel, according to estimates by the U.S. Bureau of Mines (USBM) (see Table 1 and Figure 1). The value of natural-gas production in Oregon in 1991 was $3.9 million, unchanged from 1990. The total of nearly $274 million was 16 percent greater than in 1990. Production of ferronickel at the Glenbrook Nickel Company smelter at Riddle, Oregon, nearly doubled, accounting for the largest single share of the increase. According to the USBM estimates for 1991, the value of the combined metals and industrial minerals grew by 54 percent to $131 million; of this, the value of industrial minerals grew an estimated 39 percent. The value of produced rock materials, sand, gravel, and crushed stone decreased slightly, by 6 percent, to $139 million.

EASTERN OREGON

The Bonnanza placer mine (mine site 2 [for all active mine sites see Figure 2 and Table 2]) on Pine Creek in Baker County, remains the state's largest gold producer. The company's successful reclamation efforts were honored by the Oregon Department of Geology and Mineral Industries (DOGAMI) with one of the two Outstanding Operator awards presented in 1991 (Figure 3). Bonnanza expected to exhaust its deposit by 1991; it now foresees continued operations into 1992.

Ash Grove Cement West, Inc., near Baker City, remains eastern Oregon's largest mineral producer (mine site 9). In 1991, Ash Grove produced 475,000 tons of clinker for cement, down 5 percent from 1990, and 220,000 tons of crushed limestone, the same as in 1990. The company continues to employ 105 workers, remaining a stable and sizable employer for eastern Oregon. *(Text continued on page 62)*

Table 1. *Summary of mineral production value (in millions of dollars) in Oregon for the last 20 years. Data for 1991 derived from U.S. Bureau of Mines annual preliminary mineral-industry survey and Oregon Department of Geology and Mineral Industries natural-gas statistics.*

	Rock materials[1]	Metals and industrial minerals[2]	Natural gas	Total
1972	54	22	0	76
1973	55	26	0	81
1974	75	29	0	104
1975	73	33	0	106
1976	77	35	0	112
1977	74	35	0	109
1978	84	44	0	128
1979	111	54	+	165
1980	95	65	12	172
1981	85	65	13	163
1982	73	37	10	120
1983	82	41	10	133
1984	75	46	8	129
1985	91	39	10	140
1986	96	30	9	135
1987	102	52	6	160
1988	130	48	6	184
1989	131	55	4	190
1990	148	85	4	237
1991	139	131	4	274

[1] Includes sand, gravel, and stone.

[2] For 1991, this includes cement; clays, including bentonite; copper-zinc; diatomite; gemstones, including Oregon sunstone; gold-silver; nickel; perlite; pumice; quartz; silica sand; talc, including soapstone; and zeolites.

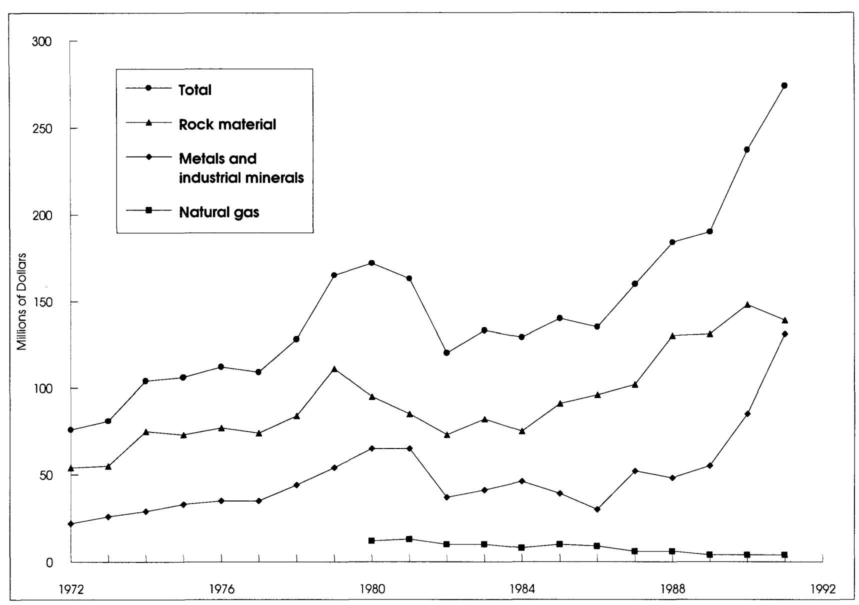
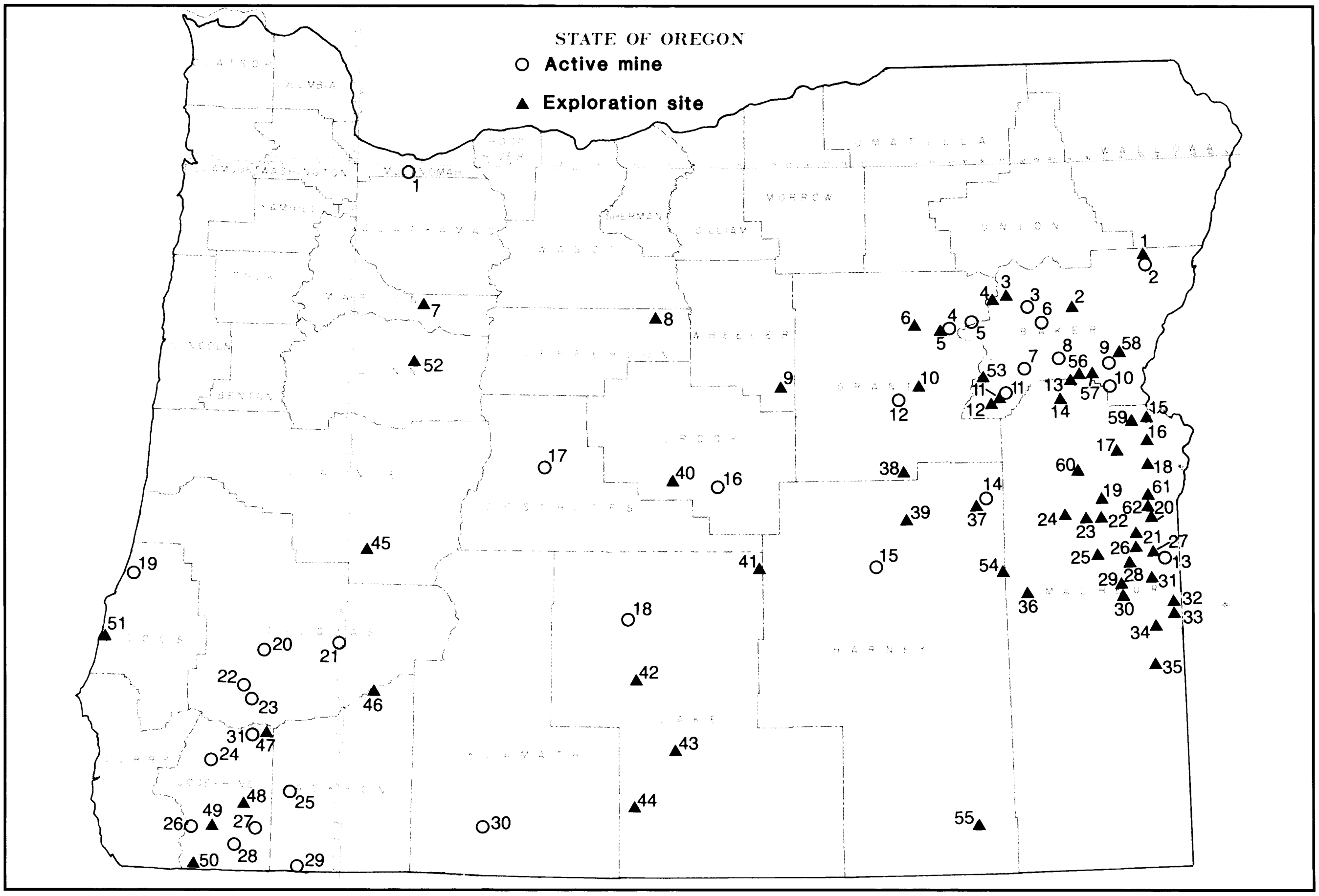


Figure 1. Summary of mineral production value in Oregon for the last 20 years. Data from Table 1.



EXPLANATION

Active Mines and Areas

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

Exploration Sites and Areas

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

Figure 2. Mining and mineral exploration sites in Oregon in 1991, excluding sand, gravel, and stone. Active mines are keyed to Table 2; exploration sites are keyed to Table 3.

Table 2. *Active mines in Oregon, 1991 (Numbers are keyed to Figure 2)*

No.	Mine name	Company	Commodity	Location	Remarks
1	—	Columbia Brick Works	Brick	Sec. 14, T. 1 S., R. 3 E. Multnomah County	24,000 yards of bentonite mined; 22.7 million bricks fired.
2	Bonnanza	Bonnanza Mining Company	Placer gold	Sec. 3, T. 7 S., R. 45 E., Baker County	—
3	Deer Creek	Cammtex International, Inc.	Placer gold	Sec. 30, T. 9 S., R. 38 E., Baker County	—
4	Big Creek	—	Placer gold	T. 10 S., R. 34 E., Grant County	—
5	Greenhorn area	—	Placer gold	Tps. 9, 10 S., R. 35 E., Baker and Grant Counties	—
6	Elk Creek	—	Placer gold	Tps. 9, 10 S., R. 39 E., Baker County	—
7	Pine Creek	—	Placer gold	T. 12 S., R. 38 E., Baker County	—
8	Dooley Mountain	Supreme Perlite Company	Perlite	Tps. 11, 12 S., R. 40 E., Baker County	Estimated 1,500 tons mined in 1991.
9	—	Ash Grove Cement West, Inc.	Cement, crushed limestone	Sec. 11, T. 12 S., R. 43 E., Baker County	Produced 475,000 tons of clinker (cement) and 220,000 tons of crushed "sugar rock."
10	Rye Valley/ Mormon Basin area	—	Placer gold	T. 13 S., Rs. 42, 43 E., Baker County	—
11	Lower Grandview	Earth Search Sciences	Lode gold	Sec. 6, T. 14 S., R. 37 E., Baker County	Reverted to exploration status exploratory drilling.
12	Canyon City Placers	Cammtex International, Inc.	Placer gold	T. 13 S., R. 32 E., Grant County	Abandoned.
13	—	Teague Mineral Products	Bentonite, zeolite	Secs. 28, 29, T. 23 S., R. 46 E., Malheur County (and nearby Idaho)	First shipment to Japan in last quarter.
14	Eagle-Picher	Eagle-Picher Industries, Inc.	Diatomite	Tps. 19, 20 S., Rs. 35, 36 E., Malheur and Harney Counties	200,000 yards mined for 1991.
15	Ponderosa Mine	—	Oregon sunstone	T. 23 S., R. 30 E., Harney County	—
16	—	Central Oregon Bentonite Co.	Bentonite	Sec. 4, T. 19 S., R. 21 E., Crook County	8,844 tons mined in fiscal 1991.
17	—	Cascade Pumice Co./Central Oregon Pumice Co.	Pumice	Tps. 17, 18 S., R. 11 E., Deschutes County	—
18	—	Oil-Dri Production Company	Diatomite	Secs. 14, 21, 23, T. 26 S., R. 16 E., Lake County	Mined 95,670 tons; processed 22,990 tons.
19	—	CooSand Corporation	Silica sand	Sec. 34, T. 24 S., R. 13 W., Coos County	Estimated 20,000 cubic yards mined.
20	Roberts Mountain	Mountain Valley Resources	Limestone	Sec. 20, T. 28 S., R. 5 W., Douglas County	Estimated 4,700 tons mined in 1991.
21	Quartz Mountain	Quartz Mountain Silica	Silica	Sec. 2, T. 28 S., R. 1 W., Douglas County	Began year's production at end of 3rd quarter.
22	Nickel Mountain	Glenbrook Nickel Company	Nickel	Secs. 28, 29, T. 30 S., R. 6 W., Douglas County	Estimated mine production 900,000 tons laterite; smelter production 16 million lb contained nickel.
23	Silver Peak Mine	Formosa Resources, Inc.	Copper, zinc, gold	Sec. 23, T. 31 S., R. 6 W., Douglas County	Shipped 3,000 tons of concentrates to Japan.
24	Galice area	—	Placer gold	Tps. 34, 35 S., R. 8 W., Josephine County	—
25	—	Bristol Silica and Limestone Co.	Silica	Sec. 30, T. 36 S., R. 3 W., Jackson County	Investment by Pacific Suma.
26	Josephine Creek area	—	Placer gold	Tps. 38, 39 S., R. 9 W., Josephine County	—
27	Jones Marble quarry	—	Limestone	Sec. 31, T. 38 S., R. 5 W., Josephine County	Closed.
28	Sucker Creek area	—	Placer gold	Tps. 39, 40 S., Rs. 6, 7 W., Josephine County	—
29	—	Steatite of Southern Oregon	Soapstone	Secs. 10, 11, T. 41 S., R. 3 W., Jackson County	Estimated 210 tons mined for 1991.
30	—	Klamath Falls Brick and Tile Co.	Brick	Sec. 19, T. 38 S., R. 9 E., Klamath County	3 million bricks in 1991 (6,000 tons).
31	Coyote Creek	Jack Smith	Placer gold	T. 33 S., Rs. 5, 6 W., Josephine County	—

Table 3. *Exploration sites in Oregon, 1991 (Numbers are keyed to Figure 2)*

No.	Mine name	Company	Commodity	Location	Remarks
1	Cornucopia Mine	UNC Corporation	Lode gold	Sec. 27, T. 6 S., R. 45 E., Baker County	—
2	White Swan	Kennecott	Lode gold	Tps. 9, 10 S., Rs. 41, 42 E., Baker County	Drilled 12 holes; dropping Virtue, keeping Gold Powder.
3	Bourne	Cracker Creek Gold Mining Co.	Gold, silver	T. 8 S., R. 37 E., Baker County	J.R. Simplot Resources dissolved precious-metals section.
4	Herculean Mine	Cable Cove Mining Company	Gold, base metals	Sec. 22, T. 8 S., R. 36 E., Baker County	Leased to Technical Metals, Inc.
5	Mammoth	Formation Capital Corporation	Gold, silver, copper	Secs. 8, 17, T. 10 S., R. 34 E., Grant County	Geophysics, mapping, and sampling.
6	Susanville	Cradle Mtn. Resources/ Amer. Copper& Nickel	Lode gold	Tps. 9, 10 S., Rs. 32, 33 E., Grant County	Property dropped by both partners.
7	Bornite	Plexus, Inc.	Copper, gold	Sec. 36, T. 8 S., R. 4 E., Marion County	Expect construction to begin in 1993.
8	Red Jacket	Bond Gold Exploration, Inc.	Lode gold	T. 9 S., R. 17 E., Jefferson County	Drilled six holes and terminated project.
9	Spanish Gulch	ASARCO, Inc.	Lode gold	T. 13 S., Rs. 24, 25 E., Wheeler County	Returned to Placer Gold Development.
10	Prairie Diggings prospect	—	Lode gold	Sec. 33, T. 13 S., R. 32 E., Grant County	No activity.
11	Record/Grouse Creek prospects	Manville Corporation	Gold, copper	T. 14 S., Rs. 36, 37 E., Baker County	Geophysics for assessment.
12	Grouse Creek prospect	Golconda Resources, Ltd.	Copper, silver	Secs. 24, 25, T. 14 S., R. 36 E., Baker County	Returned to Manville.
13	Racey property	ICAN Minerals, Ltd.	Lode gold	Tps. 12, 13 S., Rs. 40, 41 E., Malheur County	Billiton ceased operations; ICAN conducted end-of-year drilling campaign.
14	Cow Valley Butte	Cambior USA, Inc.	Lode gold	T. 14 S., R. 40 E., Malheur County	Drilled 13 holes for 7,400 ft; project terminated.
15	Kerby/ East Ridge	Malheur Mining Company	Lode gold	Secs. 22, 27, T. 15 S., R. 45 E., Malheur County	No activity.
16	Tub Mountain area	Atlas Precious Metals, Inc.; Euro-Nevada Mining Corporation; Echo Bay Exploration, Inc.	Lode gold	Tps. 16, 17 S., R. 45 E., Malheur County	Atlas holding; Euro-Nevada abandoned its property; Echo Bay properties reverted to Malheur Mining.
17	Hope Butte	Horizon Gold Shares, Inc.	Lode gold	Sec. 21, T. 17 S., R. 43 E., Malheur County	Chevron Resources dropped out; project back to exploration status.
18	Vale Butte	Atlas Precious Metals, Inc.	Lode gold	Secs. 28, 29, T. 18. S., R. 45 E., Malheur County	Drilled nine holes and abandoned property.
19	H claims	U.S. Gold	Lode gold	Secs. 2, 10, 11, T. 20 S., R. 42 E., Malheur County	Assessment work.
20	Calavera	Atlas Precious Metals, Inc.	Lode gold	T. 21 S., R. 45 E., Malheur County	Leased from Euro-Nevada.
21	Grassy Mountain	Atlas Precious Metals, Inc.	Lode gold	Sec. 8, T. 22 S., R. 44 E., Malheur County	Obtained water supply; focused on permit acquisition.
22	Harper Basin	Atlas Precious Metals, Inc.	Lode gold	T. 21 S., R. 42 E., Malheur County	Assessment by Atlas; American Copper and Nickel Company, Inc., dropped out.
23	BCMX	American Copper and Nickel Company, Inc.	Lode gold	Secs. 10, 11, 14, 15, T. 21 S., R. 41 E., Malheur County	ACNC dropped out.
24	Gold Creek area	Manville Corporation	Lode gold	Secs. 3, 4, 10, T. 21 S., R. 40 E., Malheur County	Mapping.
25	Freeze	Western Mining Corporation	Lode gold	T. 23 S., R. 42 E., Malheur County	Completed drilling with intent of dropping.
26	Burnt Mountain area	Noranda Exploration, Inc.; Echo Bay Exploration, Inc.; Sunshine Precious Metals	Lode gold	Tps. 22, 23 S., Rs. 44, 45 E., Malheur County	Noranda withdrawing; Echo Bay dropped Lucky Lady; Sunshine Precious Metals drilled and dropped Lucky G.
27	Camp Kettle	ASARCO, Inc.	Lode gold	T. 23 S., R. 45 E., Malheur County	Reconnaissance.
28	Dry Creek Buttes area	Manville Corporation/ASARCO, Inc.; Noranda Explor., Inc.	Lode gold	Tps. 23, 24 S., Rs. 43, 44 E., Malheur County	ASARCO geophysics applied to Manville assessment; Noranda dropped some, acquired other properties.
29	Jessie Page (Quartz Mountain)	MK Gold	Lode gold	Sec. 6, T. 25 S., R. 43 E., Malheur County	Chevron dropped minerals-exploration groups.
30	Red Butte	Cyprus Mineral Company	Lode gold	Secs. 26, 27, 34, 35, T. 25 S., R. 43 E., Malheur County	Hand-trenching assessment.

Table 3. *Exploration sites in Oregon, 1991 (continued)*

No.	Mine name	Company	Commodity	Location	Remarks
31	South Owyhee Ridge area	Manville Corp.; Noranda Explor., Inc.; Euro-Nevada Minerals; Atlas Precious Metals	Lode gold	Tps. 24, 25 S., R. 45 E., Malheur County	Noranda continued minimal work at Goldfinger and SR claims; Katey drilled by Atlas.
32	Bannock	Atlas Precious Metals and Manville Corp.	Lode gold	Sec. 11, T. 26 S., R. 46 E., Malheur County	Atlas drilled three holes on lease.
33	Mahogany	Cyprus Minerals and Manville Corp.	Lode gold	Secs. 25, 26, T. 26 S., R. 46 E., Malheur County	Cyprus drilled one hole to satisfy assessment.
34	Mahogany Gap and Storm	Phelps Dodge	Lode gold	Secs. 18, 19, 30, T. 27 S., R. 45 E., Malheur County	Evaluation complete
35	Jordan Valley area	Manville Corp.; Battle Mountain Explor. Co.; Nerco Explor. Co.	Lode gold	T. 29 S., R. 45 E., Malheur County	Battle Mountain reclaimed; Manville let Hillside lapse; Nerco dropped Anderson in late 1990.
36	Stockade area	BHP-Utah International/Carlin Gold; Phelps Dodge	Lode gold	Tps. 25, 26 S., R. 38 E., Malheur County	BHP-Utah returned property to Carlin Gold; PD drilled nine holes and terminated project.
37	Drewsey area (Red Butte/Pine Creek)	Battle Mountain Exploration Company	Lode gold	T. 20 S., R. 35 E., Harney County	Battle Mountain reclaimed Pine Creek.
38	Baboon Creek	Chemstar Lime, Inc.	Limestone	T. 19 S., R. 32 E., Grant County	Reverted to Blue Mountain Mining.
39	Idol City area	Golden Chest	Lode gold	Tps. 20, 21 S., R. 32 E., Harney County	—
40	Bear Creek Butte	Coeur Exploration, Inc.; Independence	Lode gold	Tps. 18, 19 S., R. 18 E., Crook County	Drilled by Coeur, returned to Independence and terminated.
41	Glass Butte	—	Lode gold	Tps. 23, 24 S., R. 23 E., Lake County	Reclaimed in 1990; no activity in 1991.
42	Summer Lake area	N.A. Degerstrom, Inc.; Tracy Gold Corp.	Lode gold	Sec. 14, T. 30 S., R. 16 E., Lake County	Returned to Tracy Gold Corporation in late 1990.
43	Paisley area	N.A. Degerstrom, Inc.; Atlas Precious Metals	Lode gold, perlite	T. 34 S., Rs. 18, 19 E., Lake County	Degerstrom returned properties to Tracy Gold Corporation; Atlas tested perlite.
44	Quartz Mountain	Pegasus Gold, Inc.; Quartz Mtn. Gold Corp.; Wavecrest Resources	Lode gold	Secs. 26, 27, 34, 35, T. 37 S., R. 16 E., Lake County	8,000 ft of drilling in 1991; final feasibility study due early 1992.
45	Bohemia District	Bond Gold Exploration, Inc.	Lode gold	T. 22 S., Rs. 1, 2 E., Lane County	Bond Gold left; exploration by unnamed company.
46	Prospect Silica	Mountain Valley Resources	Silica	T. 30 S., R. 2 E., Jackson and Douglas Counties	Exploration plan approved by Forest Service.
47	Martha Mine	Cambior USA, Inc.	Lode gold	Sec. 28, T. 33 S., R. 5 W., Josephine County	Cambior drilled 11 holes for 6,900 ft and returned property to Dragon's Gold.
48	Marble Mountain	Campman Calcite Company	Limestone	Sec. 19, T. 37 S., R. 6 W., Josephine County	Mined 900-ton test batch.
49	Eight Dollar Mountain	Doug Smith/ Lynn Wagner	Nickel laterite	T. 38 S., R. 8 W., Josephine County	Permitting of complex land situation.
50	Turner-Albright	Cominco American Resources, Inc.	Copper, zinc, gold	Secs. 15, 16, T. 41 S., R. 9 W., Josephine County	Exploring.
51	Seven Devils area	Oregon Resources	Black sands	T. 27 S., R. 14 W., Coos County	Ambitious shallow-drilling program: 549 holes
52	Quartzville	Placer Dome	Lode gold	T. 11 S., R. 4 E., Linn County	Drilled five holes; total about 2,800 ft.
53	Pole Creek	Placer Dome	Lode gold	Sec. 4, T. 13 S., R. 36 E., Baker County	Drilled five holes for total of about 2,500 ft.
54	Buck Mountain	Teck Resources/ Carlin Gold	Lode gold	T. 24 S., Rs. 36, 37 E., Harney and Malheur Counties	Drilled 16 holes in last quarter of 1991.
55	Flagstaff Butte area	Noranda Exploration	Lode gold	Sec. 5, T. 39 S., R. 37 E., Harney County	Drilled three holes for total of 2,100 ft.
56	Cave Creek	Nerco	Lode gold	T. 12 S., R. 42 E., Baker County	Drilled 10 holes; holding property.
57	Gold Ridge Mine	Golconda Resources, Ltd.	Lode gold	Sec. 16, T. 12 S., R. 43 E., Baker County	Drilled 22 holes for total of about 7,500 ft; holding property.
58	Gold Hill Mine	Golconda Resources, Ltd.	Lode gold	Sec. 1, T. 12 S., R. 43 E., Baker County	Drilled three holes for total of about 750 ft; holding property.
59	Birch Creek	Western Epithermal	Lode gold	Secs. 20, 21, T. 15 S., R. 44 E., Malheur County	Drilled four holes for total of about 1,700 ft; returning property.
60	White Mountain	White Mountain Mining	Diatoms	T. 18 S., R. 41 E., Malheur County	Applied for exploration permit.
61	Chalk Butte/Big Red	Ron Johnson, Battle Mountain Exploration	Lode gold	Sec. 15, T. 20 S., R. 45 E.; T. 20 S., R. 44 E., Malheur County	Big Red was drilled and terminated; Battle Mountain holding Chalk Butte.
62	Shell Rock Butte	Western Epithermal	Lode gold	Secs. 12, 13, T. 21 S., R. 44 E.; secs. 5-8, 17, 18, T. 21 S., R. 45 E., Malheur County	Geophysics and geochemistry; drill targets identified.

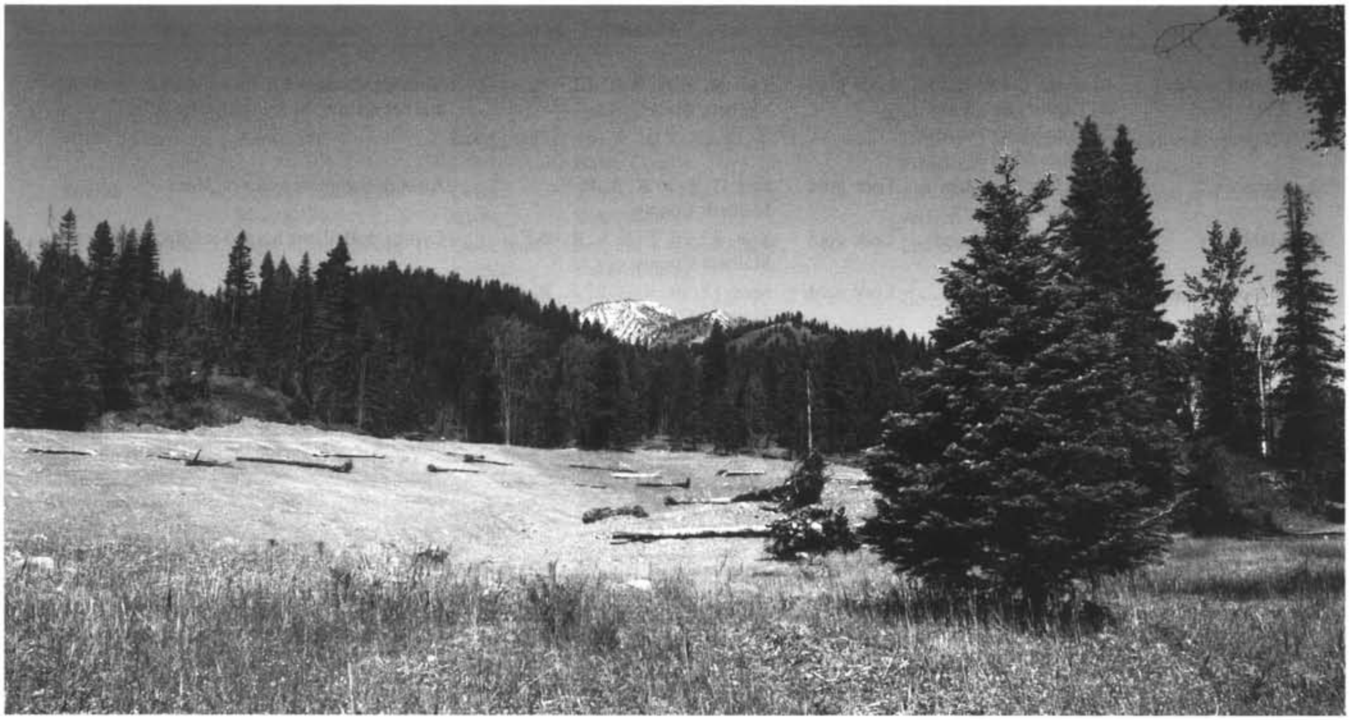


Figure 3. For its proficient reclamation at its Pine Creek operations, Bonnanza Mining Company was awarded DOGAMI's 1991 Operator of the Year Award for eastern Oregon. This was formerly a pit for placer operations.

Eastern Oregon producers continued to be major contributors to the state's industrial-minerals production. Eagle-Picher Industries (mine site 14) in Harney and Malheur Counties reported mining 200,000 yards of diatomite. Oil-Dri Production Company (mine site 18) in Lake County processed 22,990 tons of diatomite. Central Oregon Bentonite (mine site 16) in Crook County reported mining 8,800 tons of bentonite. Klamath Falls Brick and Tile (mine site 30) fired 3 million bricks from 6,000 tons of clay. Cascade Pumice and Central Oregon Pumice (mine site 17) in Deschutes County continued to dominate the nation's pumice production.

WESTERN OREGON

At Riddle, Glenbrook Nickel Company (mine site 22; see also Figure 4) produced an estimated 16 million pounds of contained nickel, nearly doubling the 1990 levels. Nine hundred thousand tons of laterite grading 1.25-1.5 percent nickel were mined from Nickel Mountain and provided 90 percent of the smelter feed in 1991. In addition, Glenbrook received its first shipment of 20,000 metric tons of test ore grading 2.4 percent nickel from New Caledonia. Glenbrook expects regular shipments of New Caledonian ore to begin in 1992. Glenbrook will produce 30 million pounds of nickel annually at peak capacity.

Formosa Exploration, Inc., in 1991 began mining zinc and copper ore from a kuroko-type massive-sulfide deposit at its Silver Peak Mine (mine site 23) near Riddle. In November, Formosa shipped its first 3,000 tons of concentrates to Japan. At year's end, operations at Silver Peak were on standby, with 28,000 tons having been mined.

In Multnomah County, Columbia Brick Works (mine site 1) mined 24,000 yards of bentonitic clay to produce nearly 23 million bricks, enough for about 570 brick houses.

Campman Calcite Company re-opened operations at the Marble Mountain Mine (exploration site 48 [for all exploration sites see Figure 2 and Table 3]) southwest of Grants Pass. A 900-ton sample was mined for shipment to Holly Sugar in Chico, California. Company owners have high hopes that Marble Mountain, which had operated from 1917 on for 50 years, would become a major limestone producer in southwestern Oregon. Planned production of up to 500,000 tons annually would help offset declining employment and tax revenues in an area beset by declining timber harvests. The reaction of local residents, however, was less than enthusiastic.

LEGISLATIVE ACTIONS

In 1991, the Oregon legislature passed two bills of major significance to the mining industry, especially precious-metals exploration: a moritorium on offshore mineral exploration, Senate Bill SB499, and the chemical process mining or cyanide heap-leaching bill, House Bill HB2244.

HB2244 governing chemical-process mining was a consensus bill with nobody happy about every aspect. The bill specified that the Oregon Department of Geology and Mineral Industries (DOGAMI) would have the lead coordination role and that multiple permits from several state agencies would remain. DOGAMI finished its rule writing on November 1, the provisions of which were hammered out and agreed to by a coalition of representatives from industry, environmental groups, and government. Early in 1992, the Oregon Mining Council (OMC) persuaded the Environmental Quality Commission (EQC) to select an independent consultant to review regulations proposed by the Oregon Department of Environmental Quality (ODEQ) for consistency with state statutes and standards. This has delayed final approval of regulations proposed by ODEQ that would affect mining operations using cyanide.

EXPLORATION HIGHLIGHTS

Exploration companies in Oregon continued to concentrate on gold. While the mood of industrial-mineral and aggregate producers remained relatively positive and unchanged from the year before, the mood of explorationists grew more somber. Anxiety over regulation reportedly contributed to the decline in exploration in Oregon, but the convulsions experienced by the precious metals industry were not restricted by state lines. Gold prices remained soft worldwide. Several companies were rocked by staff reductions and office closures; a few companies terminated their U.S. precious-metals exploration staffs altogether, including Billiton, Chevron, and Simplot. More companies terminated Oregon projects in 1991 than initiated projects, at a rate of about 2 to 1. About half of these companies left Oregon altogether, most citing an uncertain regulatory future in the state. The other half retained a foothold in the state and looked to see if the projects of Atlas (Grassy Mountain) and Plexus (Bornite) would indicate a trend for future success.

EASTERN OREGON

In Eastern Oregon, large-scale epithermal gold deposits remained the exploration target of choice. The eyes of the mining industry were on Atlas Precious Metals and its Grassy Mountain project in Malheur County (exploration site 21). A number of exploration companies adopted a wait-and-see attitude; others dropped out. Atlas developed its water supply and focused on permit acquisition at Grassy Mountain. In addition, Atlas continued to acquire and drill other properties in 1991.

A number of 1990 properties were dropped in 1991 with no subsequent activity. Cradle Mountain Resources and American Copper and Nickel both dropped the Susanville Prospect (exploration site 6) in Grant County. ASARCO dropped Spanish Gulch (exploration site 9) in Wheeler County.

Several properties in Malheur County were dropped. Cambior USA, Inc., dropped Cow Valley Butte (exploration site 14). Atlas dropped Vale Butte (exploration site 18), and American Copper and Nickel dropped BCMX (exploration site 23). Phelps Dodge completed its evaluation and terminated its Mahogany Gap and Storm projects (exploration site 34) and drilled 5,000 ft in the Stockade area (exploration site 36) before abandoning the project. Western Mining drilled and intended to drop Freeze (exploration site 25). None of these properties attracted subsequent attention.

Noranda and Sunshine Precious Metals withdrew from the Burnt Mountain area (exploration site 26); Sunshine had drilled two holes on its Lucky G claims. Nearby, luck ran out for the Echo Bay Lucky Lady, a property credited with intriguing anomalies but a discouraging proximity to Owyhee Dam. These Burnt Mountain properties remained unattended at the end of 1991.

Bond Gold reclaimed exploration sites at its Red Jacket property (exploration site 8) in Jefferson County. Independence Mining terminated its Bear Creek Butte project (exploration site 40) in Crook County, which had been drilled without success by Coeur Exploration. Degerstrom turned back its interests in the Summer Lake area (exploration site 42) in Lake County.

The following companies reported terminating their exploration programs in Oregon: American Copper and Nickel, Billiton, Bond Gold, Cambior, Chevron Resources, Coeur Exploration, Degerstrom, Echo Bay, Independence, Simplot, Teck Resources, and Western Mining, USA.

Chevron Resources reportedly terminated all of its precious-metal exploration groups in the U.S. in 1991, except for its interest in developing platinum-group metals of the Stillwater complex in Montana. Chevron Resources property interests in Oregon were acquired by Cyprus Minerals, except for Jessie Page (exploration site 29), which was acquired by MK Gold, and Hope Butte (exploration site 17), which reverted to Horizon GoldShares.

Figure 4. Glenbrook Nickel Company doubled its production at its Riddle ferronickel plant in 1991 over that of the previous year, helping to propel the value of Oregon's mineral industry to its fastest single year of growth since 1979.

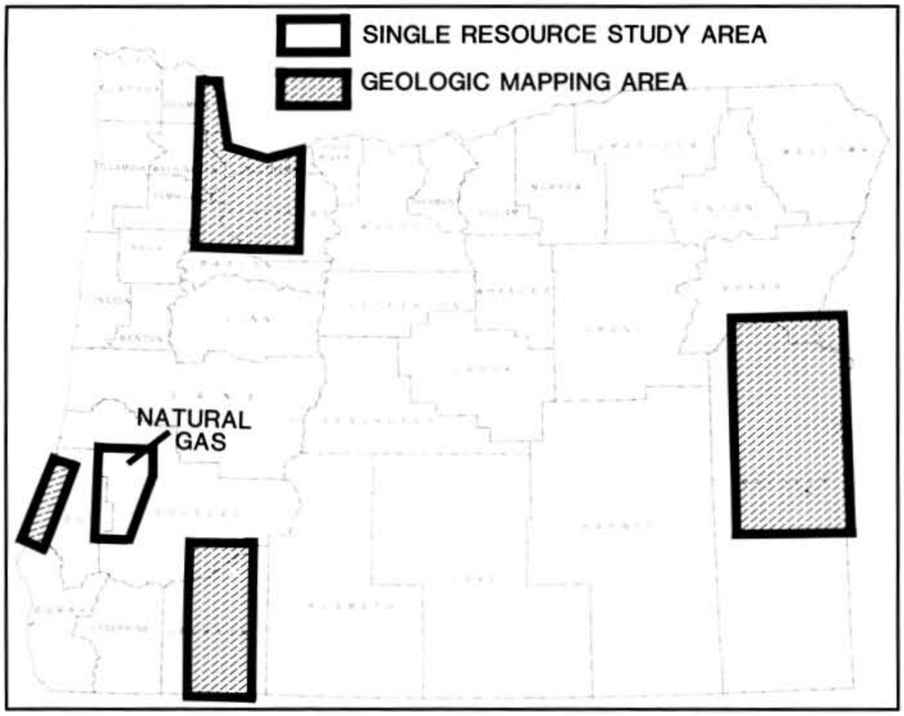


Figure 5. Areas of mapping by the Oregon Department of Geology and Mineral Industries.

Pegasus Gold committed itself to one more year at the Quartz Mountain prospect (exploration site 44) in Lake County but noted anxiety about the low grade and refractory nature of the deposit. The company reported two main ore zones containing a resource of about 55 million tons of 0.03 oz/ton gold. A final feasibility study is expected to be completed in the first half of 1992.

In contrast to the numerous departures of gold exploration companies, several new drilling programs were launched. Late in 1991, BHP-Utah began a 4,000-ft drilling program at its Quartz Mountain Basin project in the Dry Creek Buttes area south of Vale (exploration site 28). Teck Resources and Carlin Gold ventured together, temporarily, to drill at Buck Mountain (exploration site 54) in Harney and Malheur Counties. Noranda drilled three holes at its Flag property in Harney County (exploration site 55). Golconda Resources drilled a total of 25 holes at its Gold Ridge Mine (exploration site 57) and Gold Hill Mine (exploration site 58) properties in Baker County. Nerco drilled 10 holes and was retaining the property at Cave Creek in Baker County (exploration site 56).

Companies continued to extend the life of old projects. Although Billiton closed up shop, ICAN Minerals was planning an end-of-the-year drilling campaign at the Racey property in Malheur County (exploration site 13). A number of companies, among others, Atlas, ASARCO, Cyprus, Manville, and Noranda continued to apply varying levels of work to retain many different properties in eastern Oregon. Phelps Dodge retained a broad reconnaissance interest in Oregon.

Returning to Eastern Oregon in 1991 were Kennecott Exploration Company, who drilled two properties near the White Swan Mine (exploration site 2) in Baker County, and Placer Dome, who drilled at Pole Creek (exploration site 53), also in Baker County.

WESTERN OREGON

Exploration in western Oregon in 1991 was highlighted by the Plexus, Inc., Bornite project in Marion County (exploration site 7). The project has revealed a volcanic-hosted breccia pipe containing 3.5 million tons of bornite and chalcopyrite ore grading 2.2 percent copper. Coarse gold is also present, although average grades are low. Plexus completed its feasibility study in 1991 and began focusing on permit acquisition; final development will be tailored to meet permit criteria. Plexus plans to mine underground to obviate public resistance to open-pit mining. Mining rates are anticipated to be between 1,000 and 1,200 tons per day. Company officials expressed confidence in their ability to mine profitably while meeting regulatory conditions. The project has received favorable press in spite of its relative proximity to major population centers in the Willamette Valley. Initial construction is anticipated for the spring of 1993.

Following Plexus into the Western Cascades, Placer Dome descended upon a new project, Quartzville (exploration site 52) in Linn County. The target is silicic, volcanic-hosted epithermal gold. After having drilled five holes for a total of 2,800 ft, Placer Dome was holding its property.

In western Coos County (exploration site 51), Oregon Resources Corporation began and completed an ambitious shallow-drilling program to define the extent of onshore black sands. Over 16,000 ft in 549 holes were completed. Company officials reported that the results of a \$3.5-million, three-and-a-half-year exploration program were favorable. Development to production status will require an additional \$20 million.

Farther south in Josephine County, the Cambior USA, Inc., project at the Martha Mine (exploration site 47) ended in disappointment after 11 holes were drilled for a total of 6,900 ft in 1991. Cambior was unable to meet its corporate criterion of 1 million tons of 0.3 oz/ton gold in this difficult vein-gold terrane. Meanwhile, Cominco American Resources, Inc., continued to explore quietly along its Turner-Albright copper, zinc, and gold prospect in southern Josephine County (exploration site 50).

DOGAMI ACTIVITIES

Geologic mapping and mineral-resource assessment are major roles of the Oregon Department of Geology and Mineral Industries (DOGAMI), in addition to its regulatory role. DOGAMI's baseline geologic data are important to a wide variety of users, including the mineral industries. In Malheur, Baker, Jackson, and Douglas Counties, activities are directed toward geologic mapping and mineral resource assessment of the Boise and Medford 1° by 2° sheets (Figure 5). Mapping in the Portland metropolitan area and in coastal areas is directed toward earthquake-hazard assessment. Mapping in the Tyee Basin of Douglas and Coos Counties is directed toward natural-gas potential. In addition, DOGAMI provides single-resource inventories such as the state-wide pumice study expected to be published in 1992. Recently released, the Mineral Information Layer of Oregon by County (MILOC) is the most extensive available compilation of mineral resources within the state of Oregon. It consists of a computer database containing more than 7,600 mineral and aggregate sites with extensive descriptions. Current agency projects are further summarized in the report *Mission, Goals, and Activities, 1991-1997* published in 1990 and available from the agency's Portland office.

ACKNOWLEDGMENTS

The author thanks the many geologists and corporate officers that shared information for this report. □

Green apophyllite, zeolites, and quartz in Polk County, Oregon

by Jon Gladwell, 3235 SE 56th, Portland, Oregon 97206-2007

ABSTRACT

Fine green apophyllite, heulandite, and stilbite crystals have been found in a road cut near the confluence of Canyon and Rickreall Creeks in the Socialist Valley 7½-minute quadrangle in Polk County, Oregon (Figure 1). These same minerals, as well as quartz, calcite, mordenite, and other species, are also present in a barrow pit on an access road 0.1 mi west of the road cut. The sites are located on land belonging to Boise Cascade Corporation and are accessible only during approximately one month in the fall, when the company allows deer-hunting access.

DESCRIPTION AND DISCUSSION

In October of 1990 several members of the Pacific Mineral Society (Kris Dennis, Gary Hinkle, and Dan Rokosz) were conducting reconnaissance work in the Dallas, Oregon, area. At a rather weathered road cut, Dennis suggested stopping to look briefly at the cliff face and small talus slope. Rokosz found a baseball-sized nodule lined with stilbite and pearly white heulandite crystals in the debris that had weathered from the cliff. Upon closer inspection, several small, radial clusters of medium-green apophyllite crystals perched on the heulandite were noted. Further search of the scree revealed additional heulandite but no apophyllite. Inspection of the overhanging cliff face revealed a number of cavities ranging in size from 2 in. to 18 in. in largest dimension lined with heulandite crystals. No additional apophyllite was found at this point.

Soon after returning from this expedition, these gentlemen notified the author as well as other members of the Pacific Mineral Society of their findings. The author and members of the Society made several collecting trips in rapid succession, until the gate providing access to the area was closed and locked at the conclusion of the 1990 hunting season. During this period (less than a month), several hundred fine heulandite specimens were collected. However, only two or three green apophyllites of significant size were discovered, in addition to about a dozen microspecimens.

After the gate was locked, the author contacted Boise Cascade Corporation on behalf of the Society and obtained a special permit that allowed members access to the area during a five-month period in the winter and early spring. The permit was issued for the purpose of collecting sufficient specimens for study and characterization of the deposit for the historical record. During the period allowed by the permit, additional specimens were found, including approximately six more green apophyllites (Figure 2). Also, another small outcrop of pale-tan heulandite crystals was found higher up the hill, immediately west of the road cut. Prospecting in the area revealed an abandoned barrow pit west of the road cut. Cavities containing fine mordenite, colorless apophyllite, stilbite, heulandite, and quartz crystals and chalcedony rinds were found in abundance. A few small masses of green apophyllite were also found, but no crystals were recovered.

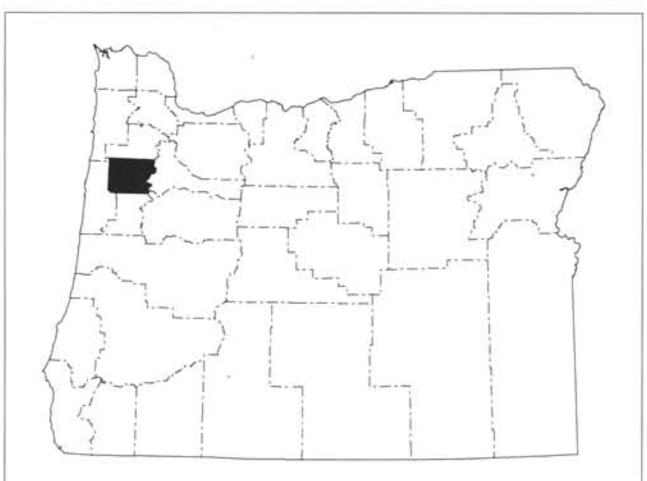


Figure 1. General location of study area. Map showing Oregon counties shows Polk County in black.

Figure 2. An opened concretion showing green apophyllite crystals on white heulandite crystals.

The study area lies along the northern bank of Rickreall Creek, due west of Dallas in Polk County, Oregon, 0.5 mi east of the confluence of Rickreall Creek with Canyon Creek, and is included in the Dallas/Polk County watershed. Access is regulated and restricted by Polk County, Boise Cascade, and the landowners along the creek. The public is generally not granted access to the watershed area except during hunting season, when vehicles are permitted past the gate but must stay on the main road. Residents of the area report that the Polk County Sheriff's Department has issued citations (resulting in stiff fines) to unauthorized visitors.

The bedrock in the area has been mapped as the lower Eocene Siletz River Volcanic Series (Snavely and Baldwin, 1948) and has since been renamed the "Siletz River Volcanics." The Siletz River Volcanics are described as "a series of basaltic flows, breccia, and pillow lavas, together with tuffaceous sedimentary beds" and are exposed "in the valleys of Rickreall, Salt, Gooseneck, Gold, Rowell, and Sunshine Creeks and in the main valley and tributaries of the Siletz River" (Baldwin, 1964). Sedimentary bedding layers are found in many sections. The lithology of the area reveals that most of the Siletz River Volcanics are composed of basaltic breccia whose fragments range from 1 to 6 in. in diameter. Some mudflow and pyroclastic material is present, and some rather well-defined flows occur as well. The unweathered basalt fragments found in the breccia are embedded in a matrix of finer particles and palagonite. The rock is occasionally cut by calcite veinlets and is usually zeolitized. Random pillow structures occur within the breccia but are seldom concentrated in any particular flow. Zeolitic mineralization does not occur throughout the basalt groundmass as it does in the breccias. The Siletz River Volcanics are largely submarine, as indicated by the pillow lavas and (fossiliferous) calcareous sedimentary rock associated with the volcanic rocks.

At the road cut, the volcanic terrane has produced a series consisting of sedimentary beds (consisting primarily of sandstone and siltstone), followed by ash flows and breccias, and capped by basalt flows. In the case of the cavities where the fine crystals were found, it has been postulated that these cavities were originally calcareous concretions that nucleated around a carbonate/apatite particle. Over time, silica particles continued to be cemented by dissolved calcite, as they were buried under accumulating sea-floor sediments. At some point, depletion of calcium ions in the interstitial fluids allowed a change from a calcite "cement" to one consisting predominantly of silica (J.J. Gray, personal communication, 1991). Later hydrothermal alteration caused the "leaching away" of the calcite "cement" in the nuclei of the concretions. A cavity was thus formed in the center of many concretions (see Figure 3), which became the place for the development of the secondary zeolitization process, including growth of the green apophyllite crystals.

Figure 3. A concretion in place with a small hole showing white heulandite.

Although all of the species described are worthy of collecting and display, it is the green apophyllite crystals at the road cut that make this locality particularly special. The apophyllite is generally found in radiating clusters and approaches an inch in diameter in the larger specimens. The color ranges from pale sea green to fine emerald. The crystals are exceptionally clear and often are enhanced by a white base of underlying heulandite. Rosettes perched directly on the gray to black country rock take on a duskier hue.

At the barrow pit, fine specimens consisting of mordenite-lined cavities up to 24 in. or more across have been collected. Oftentimes, tiny microcrystals of quartz are impaled on the mordenite hairs. Large white stilbite and heulandite crystals, often up to an inch in length, are associated with the mordenite. In some cases, mineralization commenced with a layer of blue chalcedony, which makes aesthetically pleasing specimens. Occasionally, the mordenite has been lightly stained with an amorphous iron oxide, which also enhances the specimen.

A small exposure of pale-tan heulandite crystals (the coloring due to a slight iron oxide stain) was also noted just a few hundred feet due west of the road cut, higher up the slope. These crystals are up to an inch in size and rather more weathered than those found in the road cut or barrow pit.

WARNING

Unfortunately for collectors, Boise Cascade has not been inclined to allow additional collecting in the area. At the road cut, the already dangerous overhang was further weakened by collecting efforts (see Figure 4) and, at this time, presents a serious and profound risk of falling rock. Exploratory work done at the conclusion of the permit period included efforts to spall off the most dangerous breccia overhang, with only limited success. **It must be emphasized that the road cut area presents an extreme hazard to collectors. Boise Cascade does not allow collecting at any of these sites.**

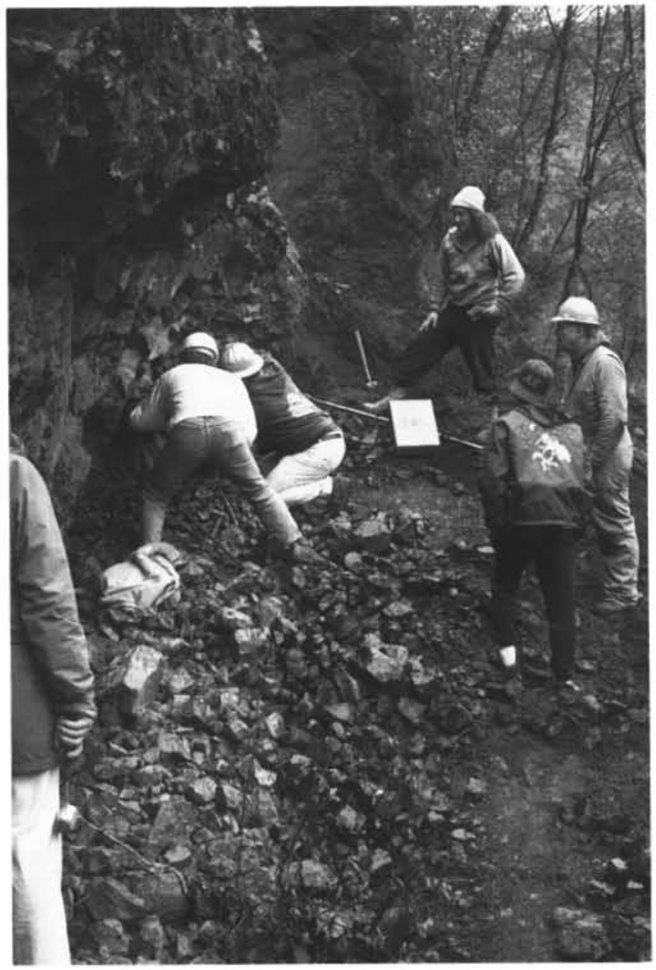


Figure 4. A sedimentary interbed overlain by basalt and containing crystal-bearing concretions is being mined by members of the Pacific Mineral Society. Note hazardous basalt overhang.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Toussaint Clay; Kris Dennis; Christopher and Ric Gibson; Gary Hinkle; Alex, Bonnie, and Karen Huang; Bill and Patrick Leach; Mickey Marks; Dan Rokosz; Bill Tompkins; Ray Schneider; and other members of the Pacific Mineral Society for their consistent support. Jerry J. Gray of the Oregon Department of Geology and Mineral Industries (DOGAMI) provided on-site explanations and advice and generously gave hours of his time to explain the geology of the area. Beverly Vogt of DOGAMI provided valuable production assistance and on-site photography. Dan Rokosz provided the excellent specimen photography. Finally, the author and the members of the Pacific Mineral Society are greatly indebted to Bill Dryden and Boise Cascade Corporation for permission to collect at the sites and for encouragement in noting these sites for the historical record.

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Amateur paleontologist thanks the professionals

Melvin S. Ashwill of Madras, Oregon, was the recipient of the prestigious Strimple Award for 1991, awarded by the Paleontological Society for outstanding contributions of an amateur to the science of paleontology. Although his acceptance speech is printed in the Journal of Paleontology, *we consider it worthwhile to share it with the readers of* Oregon Geology. *(eds.)*

Acceptance statement delivered by Melvin S. Ashwill to the Paleontological Society annual business luncheon at the Geological Society of American annual meeting in San Diego, California, October 22, 1991.

Mr. President, paleontologists of America and elsewhere.

Very briefly, I want to thank the Paleontological Society and the foresighted Strimple family for this award. I feel deeply honored. I am also very appreciative of the care and effort expended on my behalf by those who made and supported my nomination. Thank you, particularly, Steve Manchester and Ian Gordon.

I want to seize these precious few moments that I am allowed to stand before this body to tell the professional paleontologists of the world something that they know, but can bear hearing repeated—how much their help means to an amateur paleontologist. I know every one of you has helped numbers of amateurs, and gained their gratitude. However, I want these remarks to go on record as an assessment of the value of the working partnership of amateur and professional paleontologists historically. Let me mention only a smattering of those amateurs who have benefitted from the help of professionals.

More than a century ago in my neck of the woods, central Oregon, a preacher with a strong interest and some background in natural history named Thomas Condon needed help in identifying fossils. He sent a packet of fossil bones to Othniel Marsh at Yale [University]. Dr. Marsh's eyes must have widened when he found among the specimens bones of a new genus—the Eocene ancestor of the horse. Marsh published his famous paper on horse evolution and also helped Condon by not only identifying material, but by supplying him with technical papers that were of great help to the remotely located preacher. Edward Cope, Joseph Leidy, and others likewise helped Condon. This help, along with self education prepared him, so that when the University of Oregon first opened its doors, Condon was the entire geology department!

Young Charles Sternberg, as a farmer in Kansas, discovered a rich deposit of fossil leaves. Leo Lesquereux of the United States Geological Survey helped him with indentifications. Later, he got help with vertebrate fossils from Edward Cope, even spending a winter as a guest at the Cope home in New Jersey. Sternberg went on to found a veritable dynasty of paleontologists.

Back in my neck of the woods again in recent times, a talented amateur paleontogist named Douglas Emlong scoured the Miocene rocks around Newport, Oregon, for marine mammal fossils. He was immensely successful, and his contributions to science are significant. Significant also was the professional help and encouragement he received form Arnold Shotwell, Clayton Ray, and others. Tragically, Emlong is no longer with us, but another outstanding amateur paleontologist named Guy Pierson walks in his footsteps. Pierson has also put previously unknown fossil marine mammals in the hands of professionals. He, again, has been helped by some of the same people who worked with Emlong, as well as by staff members at the Los Angeles County Museum of Natural History.

As a retired music teacher, pecking on the rocks in the desert of central Oregon, I have often found myself holding a fossil in my hands that I could not identify. The corps of professional paleontologists, each member with tremendous demands on his or her time, has been unstinting in its aid.

I mentioned earlier the mentoring of Steve Manchester; in addition, listen to a partial list of paleontologists who have generously helped me: Frank Carpenter, Bruce Tiffney, Greg Retallack, Clayton Ray, David Taylor, Jack Smiley, Herb Meyer, Jane Gray, Howard Schorn, Bill Rember, Jack Wolfe, Ted Cavender, Robin Burnham, Leo Hickey, Sidney Ash, Ted Downs, Raymond Rye, Richard Thoms, Ted Fremd, and Bill Orr. In my area of work, it's a kind of "Who's Who," isn't it?

If you are an amateur in Madras, Oregon, you are three and a half hours of driving time away from the nearest science library. Guess from where help arrived in the literature quarter? My shelves hold current reprints that would have cost me thousands of dollars if I had purchased them. They were gifts from Hickey, Wolfe, Retallack, Tiffney, Ray, Burnham, Manchester, and others. The data in this literature have been of incalculable value to me.

I must share with you a remarkable story that capsulizes my points regarding professional help to amateurs:

While collecting fossil leaves at one of my favorite localities, my daughter Leslie found a striking pseudofossil. The imprint on the rock seemed to be that of an insect. One could plainly make out head, thorax, segmented abdomen, and assorted legs.

I mailed one counterpart of the imprint to the Museum of Natural History at Harvard. I also mailed a cover letter to Frank Carpenter. Carpenter at the time was at the apex of a brilliant career, and had been referred to as "the dean of paleoentomologists". The demands on his time can be imagined.

I have a letter from Carpenter in which he patiently laments that "it is unfortunate" that the specimen was not directed to the Museum of Comparative Zoology, as there are a number of museums on the campus dealing with natural history. None of us music teachers in central Oregon could have thought there would be a need for more than one! Carpenter went to great lengths to inquire about the missing package.

I mailed the counterpart. In due time it came back with a letter from Dr. Carpenter. Instead of berating an amateur who had wasted his time, he calmly stated: "I, too, thought this was a fossil insect until I put it under the microscope and saw root hairs coming from the 'legs'!"

I close with a salute to you on behalf of the thousands of amateur paleontologists worldwide. I tip my hat and thank you, the corps of professional paleontologists, for your generous help. You can never know how much it has meant to us. □

Earth science resource guide offered

The Academy of Natural Sciences of Philadelphia has published a new reference book for earth science educators, the *Resource Guide to Earth Science*.

The guide presents brief discussions of introductory earth science topics (Planet Earth—Plate Tectonics—Minerals and Rocks—Volcanoes—Earthquakes—Weathering and Erosion—Geologic Time), each with many helpful illustrations. Most of the chapters include several activities with detailed methodological instructions. A final chapter provides an extensive list for further study: publications, periodicals, field trip ideas, and national organizations and other sources of earth science information. (Unfortunately, the book appeared too early to reflect the changed address of the Oregon Department of Geology and Mineral Industries.)

Single copies of the first printing of the 75-page, spiral-bound *Resource Guide* are available free while supplies last. They may be requested in writing on school or organization letterhead paper and should be addressed to Scott Stepanski, Education Department, Academy of Natural Sciences, 1900 Ben Franklin Parkway, Philadelphia, PA 19103-1195. □

Summary of 1992 activities, Oregon Department of Geology and Mineral Industries

Focus	Activity/project	Contact persons	Objective
Geologic hazards	Earthquake hazard inventory	George Priest Ian Madin Matthew Mabey (503) 731-4100	Provide ground response maps for urban and coastal areas; seismic velocity data from cooperative bore holes; and leadership or technical assistance for earthquake scenarios, paleoseismology, active faults, workshops, and policy-centered mitigation. Partners and cooperators include USGS, METRO, PSU, U of O, OSU, ODOT, WWSC, EMD, and SSPAC.
	Coastal erosion	George Priest Dennis Olmstead Mark Neuhaus (503) 731-4100	Continue digital analysis of coastal erosion as a pilot project using historic shoreline data; evaluate results, integrate geologic considerations into model and cooperate in outreach efforts. Partners and cooperators will include FEMA, LCDC, OCZMA, and OSU.
Geologic regulation	Surface mined land reclamation	Gary Lynch Allen Throop Frank Schnitzer Doug Gallipeau (503) 967-2039	Provide for safe and environmentally sound surface mining, leading to beneficial second use in cooperation with other agencies including local government. Includes aggregate, metal mines, cyanide heap leach mines, and exploration. Cooperation with local government is being revised through rule making and revision of State Agency Coordination Agreement. Coordination with federal agencies delineated in memorandum of understanding.
	Drilling for oil, gas, and geothermal resources	Dennis Olmstead Dan Wermiel (503) 731-4100	Provide for conservation of resource, protection of environment, safety, and second beneficial use of land plus equitable distribution of revenues where necessary. Authority includes exploration, drilling, production, and reclamation. Governing Board functions as Oil and Gas Commission. Coordination with federal agencies defined in memorandum of understanding.
Geologic mapping and data collection	Northwest Oregon	George Priest (503) 731-4100	Guide and prepare geologic mapping in northwestern Oregon with emphasis on quadrangles in the Portland area, East Vancouver sheet, etc., and with emphasis on facilitating or attracting mapping efforts by cooperators in support of agency objectives.
	Southwest Oregon	Tom Wiley Frank Hladky (503) 476-2496	Conduct geologic mapping on a cooperative basis in the east-central Medford 1° x 2° sheet. Emphasis is on the Medford valley. Partners and cooperators include U of O and USGS.
	Southeast Oregon	Mark Ferns (503) 523-3133	Conduct geologic quadrangle mapping of the east half of the Boise 1° x 2° sheet for the purposes of guiding wilderness discussion, enhancing the local economy, and delineating geologic hazards. Cooperators and partners include the USGS, PSU, and the Oregon Lottery Commission. Current emphasis is on infill mapping in anticipation of a 1:100,000-scale final map product in 1993.
Public information	The Nature of Oregon Information Center	Beverly Vogt (503) 731-4444	Operate a multidisciplinary, multi-agency outlet for natural resource and outdoor recreation related information located in the new state office building for distribution of information to the public in the Portland metropolitan area for the purposes of general public education, tourism enhancement, and public service. Cooperators include natural resource agencies, Oregon Productivity Fund, and USGS.
	Oregon Geology, publications, and library	Beverly Vogt (503) 731-4100	Release agency and cooperative geologic information to a broad public in a timely and cost effective manner with publications, a subscription-based periodical, and a technical library coordinated with the State Library System.

Summary of 1992 activities, Oregon Department of Geology and Mineral Industries (continued)

Focus	Activity/project	Contact persons	Objective
Economic geology	Mineral data base for GIS, planning and policy guidance	Jerry Gray (503) 731-4100	Maintain a PC oriented database of 8,000 mines, prospects, and occurrences based on all USGS, BLM, MLR, and agency unpublished data bases designed for dBase 3+. Retrieval utilizes a variety of fields including location. Cooperators include USGS, BLM, and USFS. Applications include local planning, basin planning, and resource overviews.
	Industrial minerals	Ron Geitgey (503) 731-4100	Conduct statewide assessments and regional evaluations of industrial minerals for purposes of rural diversification. Current emphasis is on initial stages of clay studies and dimension stone studies. The need for aggregate studies is being monitored.
	Energy resources	George Priest Jerry Black (503) 731-4100	Complete final report for 1-km-deep scientific drill hole at Santiam Pass with geothermal implications, serve as source of geotechnical advice for geothermal energy, and continue natural gas assessment of southern Coast Range (Tyee Basin) with emphasis on resource targeting through reconnaissance mapping and transect development. Cooperators include USDOE, Oxbow Energy Co., BPA, landholders, DSL, Oregon Lottery, OSU, USFS, and BLM.
	Rock and mineral laboratory	Gary Baxter Chuck Radasch (503) 229-6966	Provide quantitative analytical data in support of agency programs through a cooperative lab facility focused on unique tasks with emphasis on sample preparation, quality control, correct sampling, and proper interpretation of results. Includes curation of samples and voluntary drill cores.
Selected planning	Water	Dan Wermiel (503) 731-4100	Link agency geologic mapping and data with state water quality and water quantity planning efforts through referrals and delivery of publications.
	Local government	Dennis Olmstead Dan Wermiel (503) 731-4100; also, technical assistance by regional geologists at Baker City (503) 523-3133, Grants Pass (503) 476-2496, and Portland (503) 731-4100	Oversee agency planning involvement and link planning efforts to necessary agency data bases with emphasis on periodic review and plan amendments. Roll in areas of growing need, including updated State Agency Coordination Agreement and Goal 5, is under study.
	Offshore coordination	Dennis Olmstead (503) 731-4100	Contribute to state offshore policy development through participation in OPAC.

Acronyms:

BLM	Bureau of Land Management	ODOT	Oregon Dept. of Transportation
BPA	Bonneville Power Administration	OPAC	Ocean Policy Advisory Council
DSL	Division of State Lands	OSU	Oregon State University
EMD	Emergency Services Division	PSU	Portland State University
FEMA	Federal Emergency Management Administration	SSPAC	Seismic Safety Policy Advisory Commission
GIS	Geographic Information System	U of O	University of Oregon
LCDC	Land Conservation and Development Commission	USDOE	U.S. Department of Energy
METRO	Metropolitan Service District	USFS	USDA Forest Service
MLR	Mined Land Reclamation	USGS	U.S. Geological Survey
OCZMA	Oregon Coastal Zone Management Association	WWSC	Western Washington State College

MAJOR MINERAL EXPLORATION ACTIVITY

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Cracker Creek Mine Bourne Mining Corp.	T. 8 S. R. 37 E.	Gold	Expl
Baker 1991	Aurora Ridge Western Cons. Mines	T. 10 S. Rs. 35.5, 36	Precious metals	Expl
Baker 1991	Cave Creek Nerco Exploration	Tps. 11, 12 S. R. 42 E.	Gold	App
Baker 1991	Gold Hill Golconda Resources	T. 12 S. R. 43 E.	Gold	App
Baker 1991	Gold Powder Kennecott Expl. Co.	Tps. 9, 10 S. Rs. 41, 42 E.	Gold	Expl
Baker 1991	Gold Ridge Mine Golconda Resources	T. 12 S. R. 43 E.	Gold	Expl
Baker 1992	Pole Creek Placer Dome U.S.	T. 13 S. R. 36 E.	Gold, silver	Expl
Baker 1992*	Bigelow prospect Yellow Eagle Mining	T. 7 S. R. 45 E.	Gold	Expl
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	Chromite, zircon	Expl com
Crook 1988	Bear Creek Independence Mining	Tps. 18, 19 S. R. 18 E.	Gold	Expl
Curry 1992*	Mindoro project Mindoro Corporation	T. 36 S. R. 12½ W.	Precious metals	Expl
Grant 1991	Buffalo Mine American Amex	T. 8 S. R. 35½ E.	Gold	App
Grant 1991	Canyon Mtn. Cammtex International	T. 13 S. R. 32 E.	Gold	Expl
Grant 1992	Standard Mine Bear Paw Mining	T. 12 S. R. 33 E.	Gold, copper	Expl
Harney 1990	Pine Creek Battle Mtn. Exploratn.	T. 20 S. R. 34 E.	Gold	Expl
Harney 1991	Flagstaff Butte Noranda Exploration	Tps. 3, 9 S. R. 37 E.	Gold	App
Harney 1992*	Celatom Mine Eagle-Picher Minerals	Tps. 19, 20 S. Rs. 35-37 E.	Diatoms	App
Jackson 1991*	Al Sarena Project Fischer-Watt Gold Co.	T. 31 S. R. 2 E.	Gold	App
Josephine 1992*	Eight Dollar Mountain Doug Smith	T. 38 S. R. 8 W.	Gold	Expl
Lake 1988	Quartz Mountain Wavecrest Resources.	T. 37 S. R. 16 E.	Gold	Expl
Lake 1990	Glass Butte Galactic Services	Tps. 23, 24 S. R. 23 E.	Gold	Expl
Lake 1991	8th Drilling Series Wavecrest Resources	T. 37 S. R. 17 E.	Gold	Expl
Linn 1991	Hogg Rock Oreg. St. Highw. Div.	T. 13 S. R. 7½ E.	Rock	App
Linn 1991	Quartzville Placer Dome U.S.	T. 11 S. R. 4 E.	Gold, silver	App
Malheur 1988	Grassy Mountain Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl, com
Malheur 1988	Harper Basin Project Amer. Copper and Nickel	T. 21 S. R. 42 E.	Gold	Expl
Malheur 1988	Jessie Page M.K. Gold Co.	T. 25 S. R. 43 E.	Gold	Expl
Malheur 1988	Kerby Malheur Mining	T. 15 S. R. 45 E.	Gold	Expl, com
Malheur 1989	Hope Butte Chevron Resources	T. 17 S. R. 43 E.	Gold	Expl, com
Malheur 1990	Ali/Alk Atlas Precious Metals	T. 17 S. R. 45 E.	Gold	Expl
Malheur 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E.	Gold	Expl
Malheur 1990	Freezeout Western Mining Corp.	T. 23 S. R. 42 E.	Gold	Expl
Malheur 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E.	Gold	Expl
Malheur 1990	Grassy Mtn. Regional Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl
Malheur 1990	KRB Placer Dome U.S.	T. 25 S. R. 43 E.	Gold	App
Malheur 1990	Mahogany Project Cyprus Minerals	T. 26 S. R. 46 E.	Gold	App
Malheur 1990	Racey Project Ican Minerals, Ltd.	T. 13 S. R. 41 E.	Gold	Expl
Malheur 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E.	Gold	Veg
Malheur 1990	Stockade Mountain BHP-Utah Internatl.	T. 26 S. Rs. 38, 39 E.	Gold	Expl
Malheur 1990	Stockade Project Phelps Dodge Mining	Tps. 25, 26 S. R. 38 E.	Gold	Expl
Malheur 1991	Bannock Atlas Precious Metals	T. 25 S. R. 45 E.	Gold	App
Malheur 1991	Big Red Ron Johnson	T. 20 S. R. 44 E.	Gold	Expl
Malheur 1991	Birch Creek Ronald Willden	T. 15 S. R. 44 E.	Gold	App
Malheur 1991	Deer Butte Atlas Precious Metals	T. 21 S. R. 45 E.	Gold	App
Malheur 1991	Harper Basin Atlas Precious Metals	T. 21 S. R. 42 E.	Gold	App
Malheur 1991	Quartz Mtn. Basin BHP-Utah Intl., Inc.	T. 24 S. R. 43 E.	Gold	App
Malheur 1991	Rhinehardt Site Atlas Precious Metals	Tps. 18, 19 S. R. 45 E.	Gold	Expl
Malheur 1991	Sagebrush Gulch Kennecott Exploration	Tps. 21, 22 S. R. 44 E.	Gold	App
Malheur 1991	White Mountain D.E. White Mtn. Mining	T. 18 S. R. 41 E.	Diatoms	App
Marion 1990	Bornite Project Plexus Resources	T. 8 S. R. 3 E.	Copper	App com

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

MLR office moves

The Mined Land Reclamation Office has moved to larger quarters adjacent to the old location. The new address is 1536 Queen Avenue, SE, Albany, OR 97321. The telephone number, 967-2039, remains unchanged. A fax line will be added in the near future.

Major mineral exploration activity

No major changes in mineral activity have taken place since the March issue of *Oregon Geology.* A summary of all significant exploration activity in Oregon is presented elsewhere in this issue.

Regulatory issues

A contract is being negotiated between the Department of Environmental Quality and TRC Environmental Consultants, Inc., of Englewood, Colorado, to evaluate technical aspects of operational and closure standards of chemical process mines. The final report from TRC is expected by July 1992. □

AVAILABLE PUBLICATIONS
OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

GEOLOGICAL MAP SERIES

		Price	√
GMS-4	Oregon gravity maps, onshore and offshore. 1967	4.00	
GMS-5	Powers 15-minute quadrangle, Coos and Curry Counties. 1971	4.00	
GMS-6	Part of Snake River canyon. 1974	8.00	
GMS-8	Complete Bouguer gravity anomaly map, central Cascade Mountain Range. 1978	4.00	
GMS-9	Total-field aeromagnetic anomaly map, central Cascade Mountain Range. 1978	4.00	
GMS-10	Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	4.00	
GMS-12	Oregon part of the Mineral 15-minute quadrangle, Baker County. 1978	4.00	
GMS-13	Huntington and parts of Olds Ferry 15-minute quadrangles, Baker and Malheur Counties. 1979	4.00	
GMS-14	Index to published geologic mapping in Oregon, 1898-1979. 1981	8.00	
GMS-15	Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	4.00	
GMS-16	Free-air gravity and complete Bouguer gravity anomaly maps, southern Cascades, Oregon. 1981	4.00	
GMS-17	Total-field aeromagnetic anomaly map, southern Cascades, Oregon. 1981	4.00	
GMS-18	Rickreall, Salem West, Monmouth, and Sidney 7½-minute quadrangles, Marion and Polk Counties. 1981	6.00	
GMS-19	Bourne 7½-minute quadrangle, Baker County. 1982	6.00	
GMS-20	S½ Burns 15-minute quadrangle, Harney County. 1982	6.00	
GMS-21	Vale East 7½-minute quadrangle, Malheur County. 1982	6.00	
GMS-22	Mount Ireland 7½-minute quadrangle, Baker and Grant Counties. 1982	6.00	
GMS-23	Sheridan 7½-minute quadrangle, Polk and Yamhill Counties. 1982	6.00	
GMS-24	Grand Ronde 7½-minute quadrangle, Polk and Yamhill Counties. 1982	6.00	
GMS-25	Granite 7½-minute quadrangle, Grant County. 1982	6.00	
GMS-26	Residual gravity, northern, central, and southern Oregon Cascades. 1982	6.00	
GMS-27	Geologic and neotectonic evaluation of north-central Oregon. The Dalles 1° x 2° quadrangle. 1982	7.00	
GMS-28	Greenhorn 7½-minute quadrangle, Baker and Grant Counties. 1983	6.00	
GMS-29	NE¼ Bates 15-minute quadrangle, Baker and Grant Counties. 1983	6.00	
GMS-30	SE¼ Pearsoll Peak 15-minute quadrangle, Curry and Josephine Counties. 1984	7.00	
GMS-31	NW¼ Bates 15-minute quadrangle, Grant County. 1984	6.00	
GMS-32	Wilhoit 7½-minute quadrangle, Clackamas and Marion Counties. 1984	5.00	
GMS-33	Scotts Mills 7½-minute quadrangle, Clackamas and Marion Counties. 1984	5.00	
GMS-34	Stayton NE 7½-minute quadrangle, Marion County. 1984	5.00	
GMS-35	SW¼ Bates 15-minute quadrangle, Grant County. 1984	6.00	
GMS-36	Mineral resources of Oregon. 1984	9.00	
GMS-37	Mineral resources, offshore Oregon. 1985	7.00	
GMS-38	NW¼ Cave Junction 15-minute quadrangle, Josephine County. 1986	7.00	
GMS-39	Bibliography and index, ocean floor and continental margin off Oregon. 1986	6.00	
GMS-40	Total-field aeromagnetic anomaly maps, Cascade Mountain Range, northern Oregon. 1985	5.00	
GMS-41	Elkhorn Peak 7½-minute quadrangle, Baker County. 1987	7.00	
GMS-42	Ocean floor off Oregon and adjacent continental margin. 1986	9.00	
GMS-43	Eagle Butte and Gateway 7½-minute quadrangles, Jefferson and Wasco Counties. 1987	5.00	
	as set with GMS-44 and GMS-45	11.00	
GMS-44	Seekseequa Junction and Metolius Bench 7½-minute quadrangles, Jefferson County. 1987	5.00	
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GMS-48	McKenzie Bridge 15-minute quadrangle, Lane County. 1988	9.00	
GMS-49	Map of Oregon seismicity, 1841-1986. 1987	4.00	
GMS-50	Drake Crossing 7½-minute quadrangle, Marion County. 1986	5.00	
GMS-51	Elk Prairie 7½-minute quadrangle, Marion and Clackamas Counties. 1986	5.00	
GMS-53	Owyhee Ridge 7½-minute quadrangle, Malheur County. 1988	5.00	
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GMS-59	Lake Oswego 7½-minute quadrangle, Clackamas, Multnomah, and Washington Counties. 1989	7.00	
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GMS-65	Mahogany Gap 7½-minute quadrangle, Malheur County. 1990	5.00	
GMS-67	South Mountain 7½-minute quadrangle, Malheur County. 1990	6.00	
GMS-68	Reston 7½-minute quadrangle, Douglas County. 1990	6.00	
GMS-75	Portland 7½-minute quadrangle, Multnomah, Washington, and Clark Counties. 1991	7.00	

BULLETINS

		Price	√
33	Bibliography of geology and mineral resources of Oregon (1st supplement, 1936-45). 1947	4.00	
35	Geology of the Dallas and Valsetz 15-minute quadrangles, Polk County (map only). Revised 1964	4.00	
36	Papers on Foraminifera from the Tertiary (v. 2 [parts VII-VIII] only). 1949	4.00	
44	Bibliography of geology and mineral resources of Oregon (2nd supplement, 1946-50). 1953	4.00	
46	Ferruginous bauxite, Salem Hills, Marion County. 1956	4.00	
53	Bibliography of geology and mineral resources of Oregon (3rd supplement, 1951-55). 1962	4.00	
61	Gold and silver in Oregon. 1968 (reprint)	20.00	
65	Proceedings of the Andesite Conference. 1969	11.00	
67	Bibliography of geology and mineral resources of Oregon (4th supplement, 1956-60). 1970	4.00	
71	Geology of lava tubes, Bend area, Deschutes County. 1971	6.00	
78	Bibliography of geology and mineral resources of Oregon (5th supplement, 1961-70). 1973	4.00	
81	Environmental geology of Lincoln County. 1973	10.00	
82	Geologic hazards of Bull Run Watershed, Multnomah and Clackamas Counties. 1974	8.00	
87	Environmental geology, western Coos/Douglas Counties. 1975	10.00	
88	Geology and mineral resources, upper Chetco River drainage, Curry and Josephine Counties. 1975	5.00	
89	Geology and mineral resources of Deschutes County. 1976	8.00	
90	Land use geology of western Curry County. 1976	10.00	
91	Geologic hazards of parts of northern Hood River, Wasco, and Sherman Counties. 1977	9.00	
92	Fossils in Oregon. Collection of reprints from the *Ore Bin*. 1977	5.00	
93	Geology, mineral resources, and rock material, Curry County. 1977	8.00	
94	Land use geology, central Jackson County. 1977	10.00	
95	North American ophiolites (IGCP project). 1977	8.00	
96	Magma genesis. AGU Chapman Conf. on Partial Melting. 1977	15.00	
97	Bibliography of geology and mineral resoures of Oregon (6th supplement, 1971-75). 1978	4.00	
98	Geologic hazards, eastern Benton County. 1979	10.00	
99	Geologic hazards of northwestern Clackamas County. 1979	11.00	
100	Geology and mineral resources of Josephine County. 1979	10.00	
101	Geologic field trips in western Oregon and southwestern Washington. 1980	10.00	
102	Bibliography of geology and mineral resources of Oregon (7th supplement, 1976-79). 1981	5.00	
103	Bibliography of geology and mineral resources of Oregon (8th supplement, 1980-84). 1987	8.00	

MISCELLANEOUS PAPERS

		Price	√
5	Oregon's gold placers. 1954	2.00	
11	Articles on meteorites (reprints from the *Ore Bin*). 1968	4.00	
15	Quicksilver deposits in Oregon. 1971	4.00	
19	Geothermal exploration studies in Oregon, 1976. 1977	4.00	
20	Investigations of nickel in Oregon. 1978	6.00	

SHORT PAPERS

		Price	√
25	Petrography of Rattlesnake Formation at type area. 1976	4.00	
27	Rock material resources of Benton County. 1978	5.00	

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SPECIAL PAPERS

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2 Field geology, SW Broken Top quadrangle. 1978	5.00	
3 Rock material resources, Clackamas, Columbia, Multnomah, and Washington Counties. 1978	8.00	
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5 Analysis and forecasts of demand for rock materials. 1979	4.00	
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8 Geology and geochemistry of the Mount Hood volcano. 1980	4.00	
9 Geology of the Breitenbush Hot Springs quadrangle. 1980	5.00	
10 Tectonic rotation of the Oregon Western Cascades. 1980	4.00	
11 Theses and dissertations on geology of Oregon. Bibliography and index, 1899-1982. 1982	7.00	
12 Geologic linears, N part of Cascade Range, Oregon. 1980	4.00	
13 Faults and lineaments of southern Cascades, Oregon. 1981	5.00	
14 Geology and geothermal resources, Mount Hood area. 1982	8.00	
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16 Index to the *Ore Bin* (1939-1978) and *Oregon Geology* (1979-1982). 1983	5.00	
17 Bibliography of Oregon paleontology, 1792-1983. 1984	7.00	
18 Investigations of talc in Oregon. 1988	8.00	
19 Limestone deposits in Oregon. 1989	9.00	
20 Bentonite in Oregon: Occurrences, analyses, and economic potential. 1989	7.00	
21 Field geology of the NW¼ Broken Top 15-minute quadrangle, Deschutes County. 1987	6.00	
22 Silica in Oregon. 1990	8.00	
23 Forum on the Geology of Industrial Minerals, 25th, 1989, Proceedings. 1990	10.00	
24 Index to the first 25 Forums on the Geology of Industrial Minerals, 1965-1989. 1990	7.00	

OIL AND GAS INVESTIGATIONS

	Price	√
3 Preliminary identifications of Foraminifera, General Petroleum Long Bell #1 well. 1973	4.00	
4 Preliminary identifications of Foraminifera, E.M. Warren Coos County 1-7 well. 1973	4.00	
5 Prospects for natural gas, upper Nehalem River Basin. 1976	6.00	
6 Prospects for oil and gas, Coos Basin. 1980	10.00	
7 Correlation of Cenozoic stratigraphic units of western Oregon and Washington. 1983	9.00	
8 Subsurface stratigraphy of the Ochoco Basin, Oregon. 1984	8.00	
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10 Mist Gas Field: Exploration/development, 1979-1984. 1985	5.00	
11 Biostratigraphy of exploratory wells, western Coos, Douglas, and Lane Counties. 1984	7.00	
12 Biostratigraphy, exploratory wells, N Willamette Basin. 1984	7.00	
13 Biostratigraphy, exploratory wells, S Willamette Basin. 1985	7.00	
14 Oil and gas investigation of the Astoria Basin, Clatsop and northernmost Tillamook Counties, 1985	8.00	
15 Hydrocarbon exploration and occurrences in Oregon. 1989	8.00	
16 Available well records and samples, onshore/offshore. 1987	6.00	
17 Onshore-offshore cross section, from Mist Gas Field to continental shelf and slope. 1990	10.00	

MISCELLANEOUS PUBLICATIONS

	Price	√
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	6.00	
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	11.00	
Geothermal resources of Oregon (published by NOAA). 1982	4.00	
Index map of available topographic maps for Oregon published by the U.S. Geological Survey	Free	
Bend 30-minute quadrangle geologic map and central Oregon High Cascades reconnaissance geologic map. 1957	4.00	
Lebanon 15-minute quad., Reconnaissance geologic map. 1956	4.00	
Mist Gas Field Map, showing well locations, revised 1992 (Open-File Report O-92-1, ozalid print, incl. production data)	8.00	
Northwest Oregon, Correlation Section 24. Bruer and others, 1984 (published by AAPG)	6.00	
Oregon rocks and minerals, a description. 1988 (DOGAMI Open- File Report O-88-6; rev. ed. of Miscellaneous Paper 1)	6.00	
Mining claims (State laws governing quartz and placer claims)	Free	
Back issues of *Ore Bin/Oregon Geology*, 1939-April 1988	1.00	
Back issues of *Oregon Geology*, May/June 1988 and later	2.00	
Color postcard: Oregon State Rock and State Gemstone	1.00	

Separate price lists for open-file reports, tour guides, recreational gold mining information, and non-Departmental maps and reports will be mailed upon request. The Department also sells Oregon topographic maps published by the U.S. Geological Survey.

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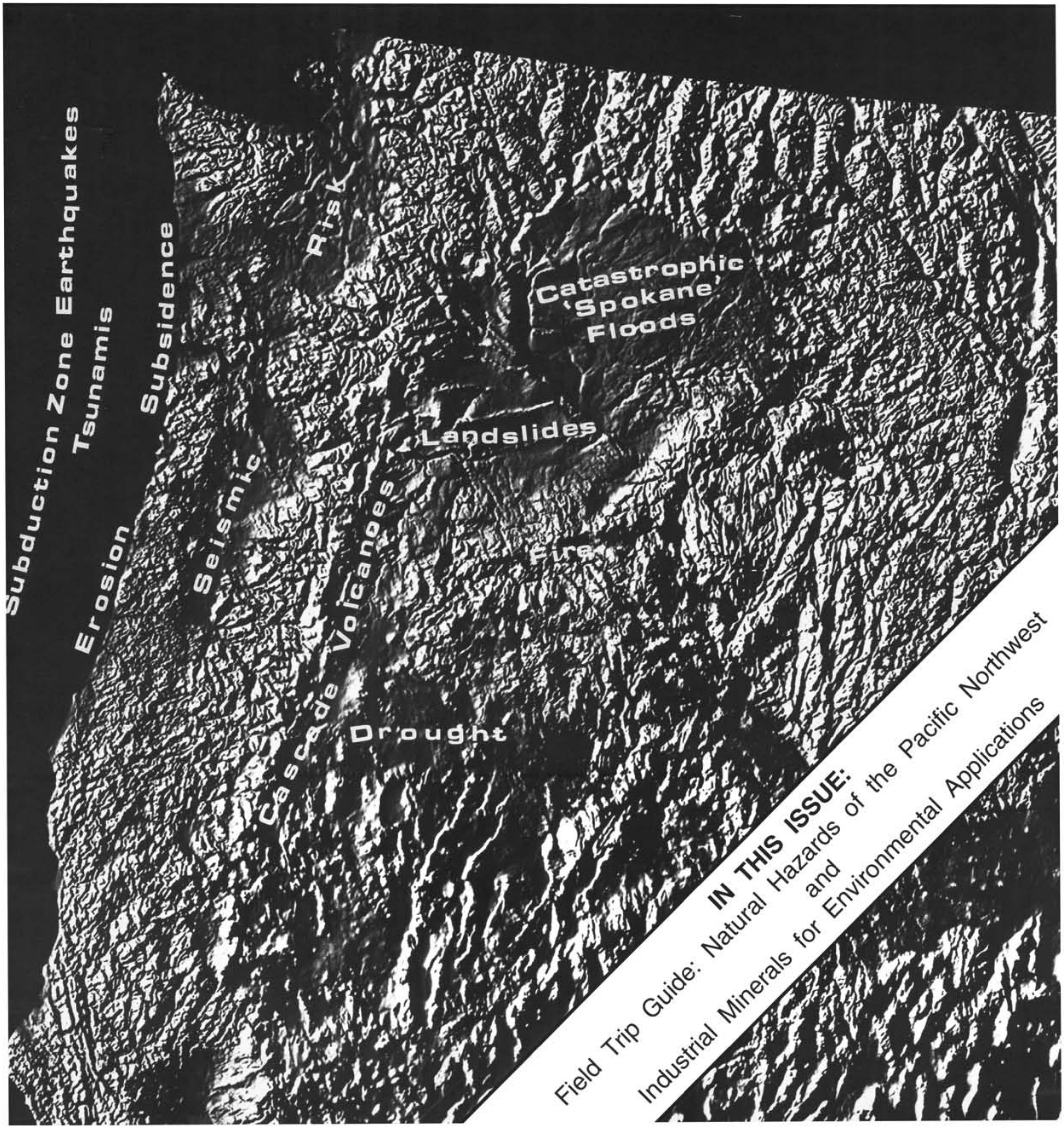

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Field Trip Guide: Natural Hazards of the Pacific Northwest
and
Industrial Minerals for Environmental Applications

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Information for contributors

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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*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

Cover photo

Digital elevation model (DEM) of the Pacific Northwest, showing areas and types of natural hazards related to the geology of the region. Field trip guide beginning on next page leads to points in Oregon and southwestern Washington where the effects of such hazards can be observed. Illustration courtesy of the U.S. Geological Survey.

OIL AND GAS NEWS

Drilling underway at Mist Gas Field

During May, Nahama and Weagant Energy Company of Bakersfield, California, began a multi-well drilling program at the Mist Gas Field, Columbia County, Oregon. The first well drilled, Columbia County 23-31-65, located in SW¼ sec. 31, T. 6 N., R. 5 W., reached a total depth of 2,272 ft and is currently suspended. Drilling operations have also been completed at the second well, Columbia County 43-33-75, located in SE¼ sec. 33, T. 7 N., R. 5 W., and the well is also suspended. Taylor Drilling Company, Chehalis, Washington, is the drilling contractor.

NWPA elects Board

The Northwest Petroleum Association (NWPA) announced the results of the elections to the Board for 1992-1993. The officers now are Jack Meyer, President; Nancy Ketrenos, Vice President; Dick Bowen, Secretary; Todd Thomas, Treasurer; and Lanny Fisk, Past President. Directors are Peter Hales, Western Washington; Thomas Deacon, Land; Williams Holmes, Legal; and John Newhouse and Dan Wermiel, At-large.

The NWPA is an organization of persons interested in oil, gas, and geothermal energy resources in the Pacific Northwest. Meetings with a speaker are held each month, and an annual field symposium is held each fall. This year, the field symposium is entitled "New Exploration Concepts and Opportunities for the Pacific Northwest." It will be held on October 11-13, 1992, in Lincoln City, Oregon. Contact the NWPA, P.O. Box 6679, Portland, Oregon 97228-6679, for further information.

Oregon DOE revising rules

The Energy Facilities Siting Council (EFSC) of the Oregon Department of Energy (ODOE) is revising its rules pertaining to the siting of energy facilities in Oregon. These rules affect a variety of energy facilities in Oregon, including underground natural-gas storage projects and pipelines. For more information on the proposed EFSC rules, contact David Stewart-Smith, ODOE, 625 Marion Street NE, Salem, OR 97310, phone (503) 378-4040.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
469	Nahama and Weagant CC 31-15-65 36-009-00294	NE¼ sec. 15 T. 6 N., R. 5 W. Columbia County	Permit; 2,800.
470	Nahama and Weagant CC 43-33-75 36-009-00295	SE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Permit; 2,550.
471	Nahama and Weagant Wilson 11 A-5-65 36-009-00296	NW¼ sec. 5 T. 6 N., R. 5 W. Columbia County	Permit; 3,500.
472	Nahama and Weagant CC 41-33-75 36-009-00297	NE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	Application; 2,850.

□

Correction

In the last (May) issue, on page 68 of the summary of activities of the Oregon Department of Geology and Mineral Industries, geologic mapping for southeastern Oregon should, of course, have referred to the mapping of the **west** half of the Boise 1° by 2° sheet. Thanks to Allen Agnew for catching the error!

Natural hazards of the Pacific Northwest, past, present, and future—a field trip guide for western Oregon and Mount St. Helens

by Charles L. Rosenfeld, Associate Professor, Department of Geosciences, Oregon State University, Corvallis, Oregon 97331

INTRODUCTION

The United States is the host nation for the 27th International Geographical Congress, an event that occurs at four-year intervals. Oregon State University is the host institution for the Study Group on Geomorphological Hazards, whose members will participate in an excursion and symposium focused on hazard analysis, response, and planning in the Pacific Northwest during August 1-7, 1992.

The following article traces, in a summary fashion, the route of this excursion (Figure 1). (Readers may wish to break it into several day-long trips at their own discretion.—*ed.*) The excursion highlights many of the natural hazards that have been recognized and studied in northwestern Oregon and southwestern Washington.

It is generally recognized that the setting of this region, with its tectonically active plates and volcanoes, its dynamic rivers, and its high-energy coastline, naturally concentrates numerous geomorphic processes posing hazards to human occupancy. Scientists, engineers, and planners, who recognize the significance of past events, have been successful at limiting the impacts of recent catastrophic events and helping to prepare the region for the future. In this light, we welcome Chairman Professor Clifford Embleton of King's College, London, U.K., and the distinguished international membership of this study group to share our observations, insights and concerns about the nature of hazards in our environment. We laud their efforts on behalf of the United Nation's International Decade for Natural Hazards Reduction (IDNHR).

THE REGION

The physiography and geology of the region are dominated by an active plate margin. Spreading from the Juan de Fuca and Gorda Ridges, the Juan de Fuca Plate converges on the North American Plate along the Cascadia Subduction Zone, which extends from the Queen Charlotte Islands of southern British Columbia southward for over 1,000 km (600 mi) to Cape Mendocino in northern California

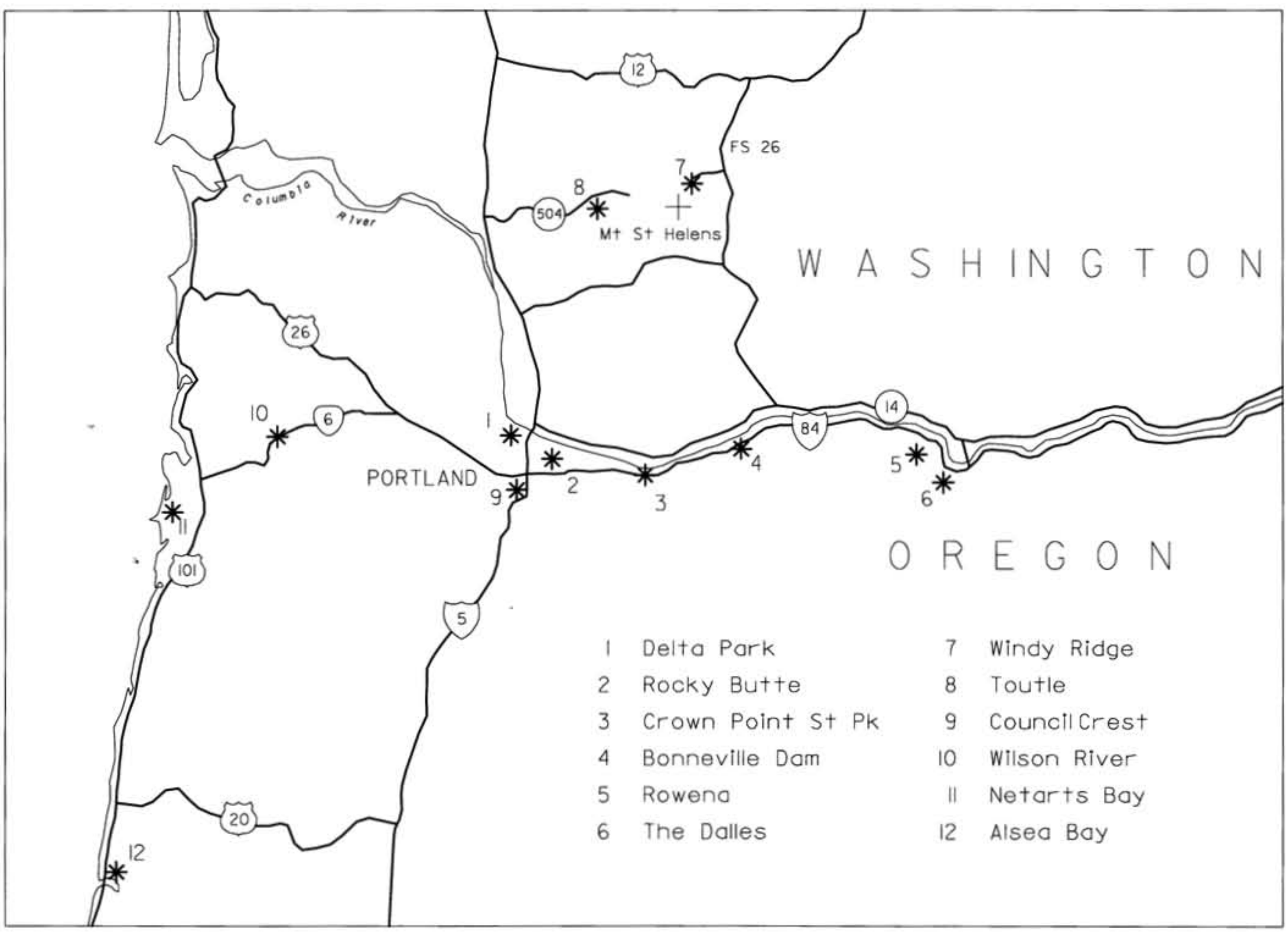


Figure 1. Location map showing stops of field trip.

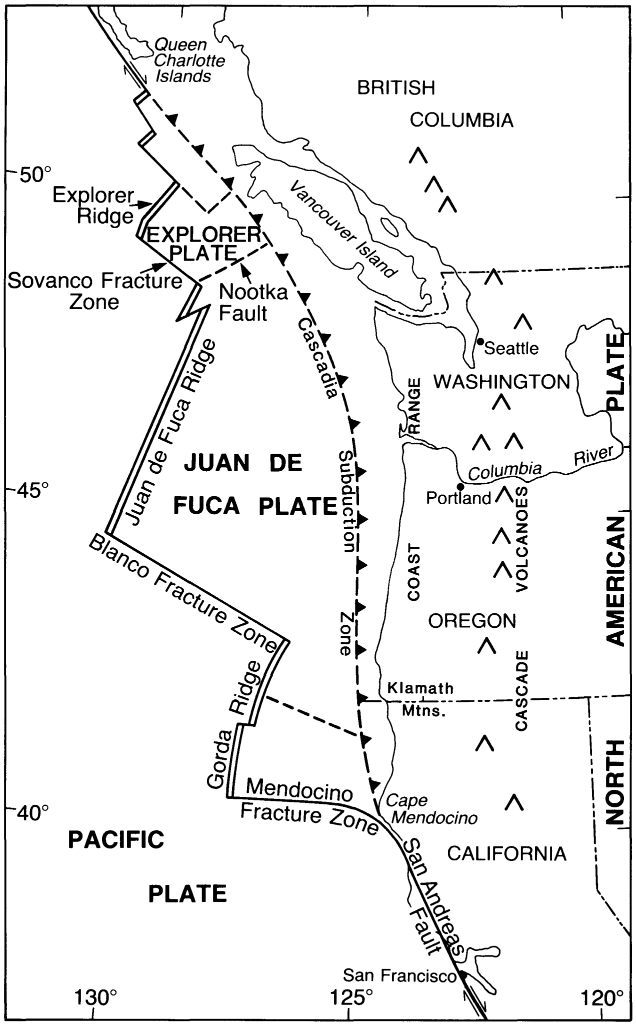


Figure 2. Plate-tectonic map of the Pacific Northwest. The active subduction of the Juan de Fuca Plate, estimated at 40 mm/yr, dominates the tectonic activity of the region and affects both its seismicity and volcanic activity. From Madin (1989).

(Figure 2). Seismic activity defines the geometry of the subducting Juan de Fuca Plate beneath western Washington and British Columbia. In the past, the nature of the subduction—seismic or aseismic—was in dispute. Recently discovered geologic evidence strongly suggests that the subduction convergence is accomplished seismically, i.e., accompanied by earthquakes (Peterson and others, 1988; Madin, 1989).

The deformed sedimentary rocks and the igneous intrusions of the Coast Range stand as testimony to the dynamics of this continental margin, as do the Cascade volcanoes—highlighted by the 1980 eruption of Mount St. Helens: Both ranges are evidence of the continuous production of magma from the remelted sea floor.

The mountain ranges that block the abundant moisture from the Pacific Ocean produce orographic precipitation resulting in the lush coniferous rain forests of the coast and the deep snow packs common to the Cascades. Thus, the tectonic and climatic settings of the Pacific Northwest reflect a dynamic environment, subjected to strong endogenetic and exogenetic energy and producing an awesome array of physical processes.

When active processes occur in a developing landscape, the consequences can be catastrophic. It is with this certain knowledge that we explore the cataclysms of the recent past, in order to contain the effects of future natural disasters. Since the "written" historical record of the Pacific Northwest is less than 200 years old, scientists must explore the nature of those high-magnitude/low-frequency events that have affected much of the region in its "pre-historic" past. The security of the population and economy of the region depend on cautious assessments and careful planning.

FIELD TRIP STOP 1. THE VANPORT FLOOD

We begin our exploration of the natural hazards of the Pacific Northwest at Portland's Delta Park near the Interstate Bridge to Vancouver, Washington (Stop 1, Figure 1). This is the site of one of the most catastrophic flood events in this region's recent history, the Vanport flood of 1948. Floods are a nearly universal problem. In the Pacific Northwest, the annual spring snowmelt accelerated by warm rainfall is the primary cause of overbank flows on most of this region's rivers.

On Sunday morning, May 30, 1948, Memorial Day, the gauge on the Columbia River at Vancouver, Washington, read 8.65 m (28.3 ft), more than 4 m (13 ft) above flood stage. By sunset, across the river, the 18,700 residents of Vanport, Oregon, were homeless as the Columbia inundated its flood plain in the second largest flood on record.

The Columbia River basin encompasses 666,000 km^2 (259,000 mi^2), draining parts of Oregon, Washington, Idaho, Montana, Wyoming, Utah, Nevada, and British Columbia. Approximately 75 percent of the region's precipitation falls in the winter months, from November to April, with a significant portion occurring as snow at the higher elevations. The Columbia River's annual hydrograph peaks in May or June, reflecting the culmination of the period of maximum snowmelt runoff. Most major historical floods on the Columbia were the result of spring snowmelt (Pacific Northwest River Basins Commission, 1971).

On April 1, 1948, the water content of the snowpack was estimated to be 97 percent of normal (Pacific Northwest River Basins Commission, 1971). Spring was late that year, with cyclonic storms bringing sizable amounts of precipitation. On May 1, the water content of the snowpack exceeded that measured in April. By mid-May, spring had finally arrived with such force that the subnormal temperatures of April were replaced by above-normal ones. A two-week period of warm weather was capped by rain, occurring in extremely heavy downpours locally on May 28 and 29.

Vanport was the largest federal housing project in the United States (Maben, 1987). Located on the flood plain of the Columbia River in north Portland, the city was within Peninsula Drainage District Number One, a low-lying area between the Columbia and Willamette Rivers. While it was considered protected, in reality the dikes surrounding the area were merely highway and railroad fills. None had been constructed to serve as levees for flood protection. But on May 30, 1948, authorities advised the residents not to panic—"the dikes are holding."

At 4:17 p.m. on May 30, a 6-ft break opened on the west dike, which consisted of railroad fill (Figure 3, point A). Within minutes it widened to 150 m, allowing a wall of water 3 m high to surge through the area (Maben, 1987). Buildings collapsed, and cars were overturned as the Columbia River flooded the district. The sloughs temporarily slowed the onrush by absorbing the water, but as they filled, the waves again surged eastward, inundating the city of Vanport.

Within two hours, Vanport was completely destroyed. At midnight, the water level within the district stood at 5 m (15 ft). Many apartment buildings floated on the waves, torn intact from their foundations. The losses were magnified by the fact that the waters had only one exit from the City's street network.

On May 31, the Denver Avenue levee on the eastern margin of the district failed (Figure 3, point B), flooding the western portion of neighboring Peninsula Drainage District Number Two. Four hours later, District Two was completely flooded when the

Union Avenue fill also gave way (Figure 3, point C). Highways, railroads, and navigation facilities that provided access to Portland from the north, east, and west were disrupted. Miraculously, only 15 lives were lost during the Vanport flood.

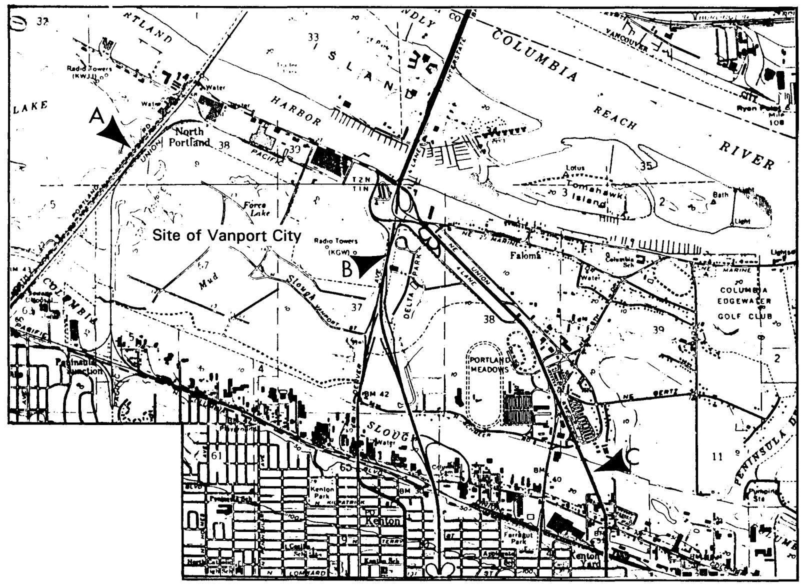


Figure 3. Location of former Vanport City and of the sites of progressive failure of (A) railroad fill on May 30, 1948; (B) Denver Avenue fill on May 31; and (C) Union Avenue fill later that same day.

Peak discharge of the Columbia River reached 28.3 million liters/sec (1.0 million ft^3 per second) at the maximum flood stage when it crested at 9.2 m (30.2 ft) on June 1. The river remained above flood stage for 26 days and at bankfull stage for 51 days.

Today, Peninsula Drainage Districts Numbers One and Two are owned by the City of Portland and have been subject to a reversal in zoning. District One, the former site of Vanport, is now zoned for parks and recreational use with a race track, radio towers, a golf course, and a wildlife refuge. With improved levees, District Two now contains recreational parks as well as a commercial area consisting of a business park, shopping facilities, restaurants, and a horse race track. However, the flood risk rating for District Two is predominantly 1-0.2 percent return frequency, with low-lying areas rated at the 1-percent return frequency, as is District One.

This "nonstructural" approach to flood mitigation is consistent with the Flood Insurance Program administered by the Federal Emergency Management Administration (FEMA). This program encourages the nonresidential use of flood-prone areas by providing low-cost flood insurance to property owners but also imposing restrictions on the reoccupancy of flood-prone areas, including "flood proofing" of buildings and minimum elevation for residential structures. Since 1948, additional flood-control capacity has been added by dams on the upper Columbia River, so that the flooding threat to the Portland area is significantly reduced.

Exit Delta Park and drive east along Marine Drive, follow signs onto Interstate 205 (south), then exit at NE Halsey (westbound). Turn north on 92nd Avenue to Rocky Butte Road and Stop 2 at Joseph Wood Hill Park atop Rocky Butte.

FIELD TRIP STOP 2. SPOKANE FLOODS

Floods of much greater magnitude than even the largest Columbia River seasonal floods played a major role in shaping the Portland landscape. During the Pleistocene epoch, the Spokane Floods (also referred to as the Missoula Floods) surged westward out of glacial Lake Missoula through northern Idaho and eastern Washington and down the Columbia Gorge, producing a heavily scoured region in eastern Washington that is called the "Channeled Scabland" and temporarily filling the Willamette Valley as far south as Eugene (Figure 4).

Lake Missoula formed when a lobe of the Cordilleran ice sheet dammed the Clark Fork River in northwestern Montana. As the ice lobe waned, the ice dam collapsed, releasing 2,000 km^3 (500 mi^3) of water (Price, 1987). Estimates indicate that the flood flow velocities reached 30 m/sec (100 ft/sec) along constrictions in the Gorge, with a discharge of nearly 7 km^3/h (1.66 mi^3/h) (Baker and Nummedal, 1978). As the debris- and ice-laden water surged into the lower Columbia River, it scoured out a channel 100 m (330 ft) deep beneath the present river bed and flooded almost 800 km^2 (300 mi^2) of the Willamette Valley. The water level in the Portland region rose to 120 m (400 ft), and as the flood subsided, sediments accumulated to a depth of 75 m (250 ft).

That several floods occurred as the Cordilleran ice sheet waxed and waned throughout the Pleistocene is evidenced by the terraces found throughout Portland. Five distinct terrace levels are located at 45 m, 60 m, 250 m, 88 m, and 100 m (150 ft, 200 ft, 250 ft, 290 ft, and 330 ft, respectively) above sea level and are composed of unconsolidated sand and gravel with an occasional granitic erratic (Price, 1987). The University of Portland is situated on the lowest terrace located in north Portland, with the higher terraces found in east Portland. As the floods exited the Columbia Gorge, they surrounded Rocky Butte, forming a depositional delta with two lag bars to the west, and scoured a dry channel, Sullivan Gulch, into the gravels in the area now occupied by Interstate 84 and the rapid-transit system (Price, 1987). Figure 5 shows the location of this delta, the bars, and the scour channel, along with several of the terraces.

Return to I-205 (north), then exit eastbound on I-84. Continue eastward for 21 km (13 mi) to Corbett, then follow the Columbia River Scenic Highway east to Crown Point State Park.

FIELD TRIP STOP 3. COLUMBIA GORGE

The scour effect of the Spokane Floods greatly altered the stream valley that traversed the Cascade Range before the deluge. The flood waters entered this canyon at The Dalles, cresting at over 300 m (1,000 ft) while scouring the local basalts to 70 m (225 ft) below sea level. The powerful torrents stripped soils and plucked bedrock along the canyon, leaving oversteepened walls, prone to mass wasting. The floods rose to overtop 300-m (1,000-ft) bluffs at the east end, dropping to 275 m (900 ft) by Hood River and about 180 m (600 ft) at the Crown Point overlook. The numerous water falls that descend from the 150-m (450-ft) elevation attest to the widening of the Gorge by the Spokane Floods. The steep walls are especially unstable along the north side of the river between Washougal and Dog Mountain, where the old volcanic ash and mudflow deposits of the Eagle Creek and Ohanapecosh Formations comprise the bedrock—in contrast to the resistant Columbia River basalt that forms the south rim and Crown Point. Several of the major slides that may be seen from the Crown Point overlook include a basalt slide block at Rooster Rock (immediately west of the overlook) and the large headwalls of the Skamania slide, which exposes the Eagle Creek Formation across the Gorge to the north. The large Cascade slide may be seen further upstream on the north end of Bonneville Dam (Figure 6).

Exit Crown Point and continue eastwards on the Scenic Highway, rejoining I-84 east of Dodson. Turn off at Bonneville Dam.

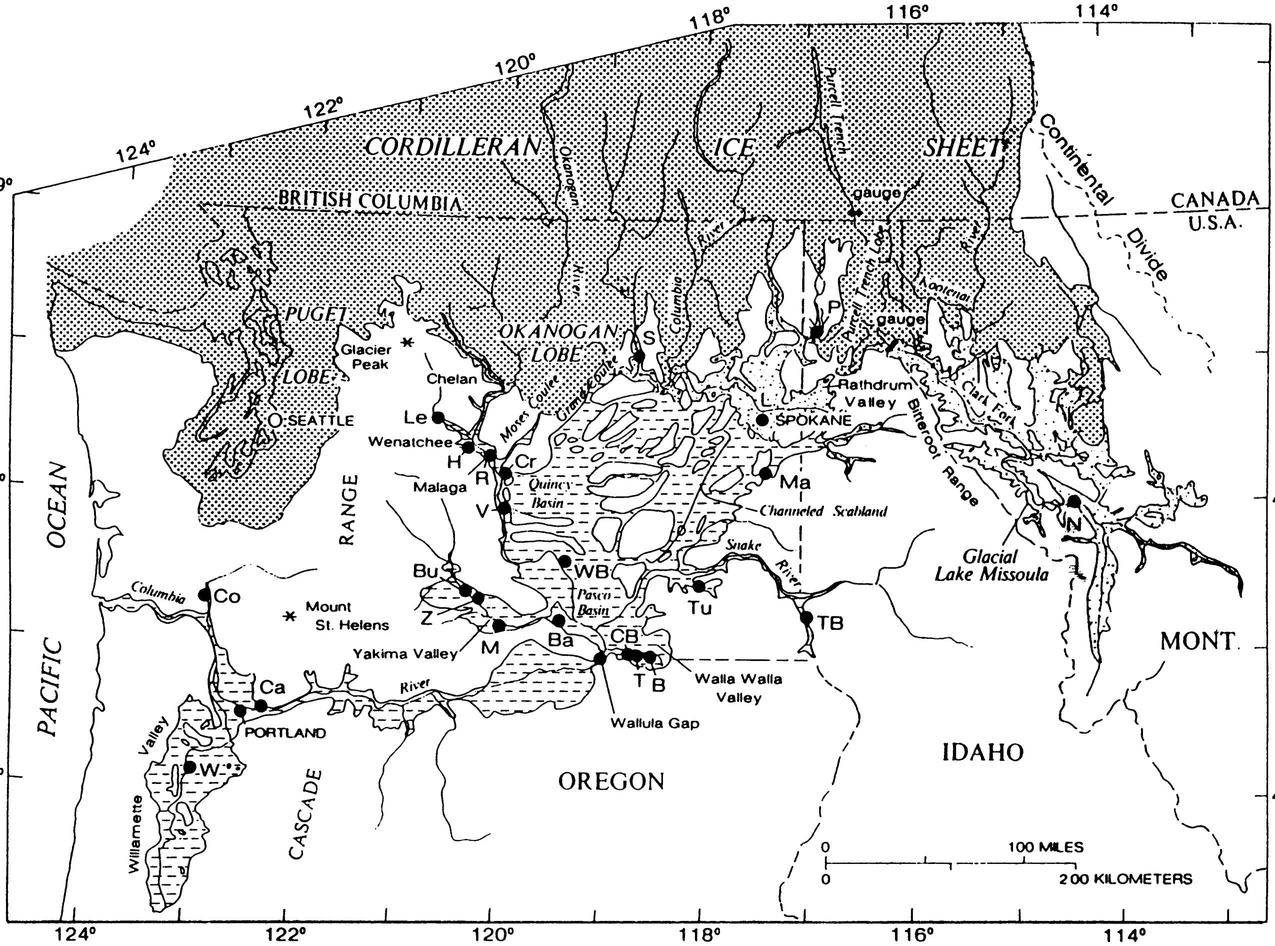
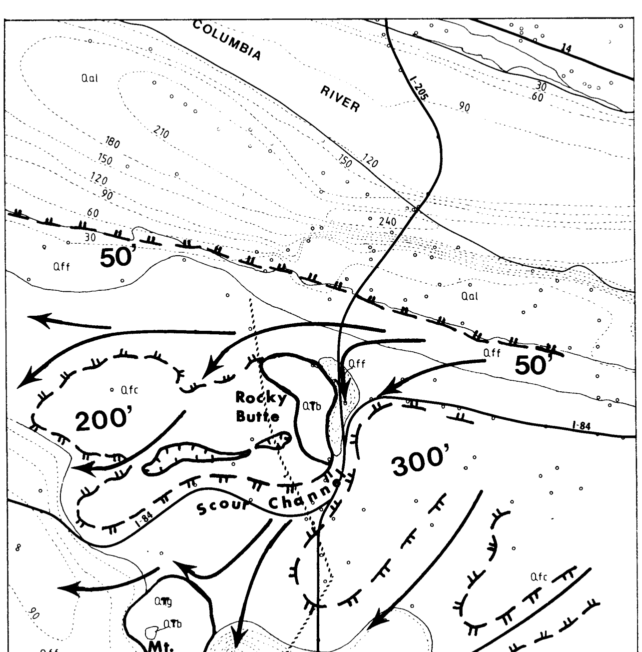


Figure 4. Regional extent of the Spokane floods during the Pleistocene, showing extent of glacial ice (densely dotted), glacial lakes Missoula and Columbia (light dots), and flooded areas (dashed pattern). Reproduced with permission from Allen and others (1986).



←Figure 5. Deflection of Spokane flood currents by the resistant basalts of Rocky Butte and Mount Tabor with lag bars to the west of Rocky Butte and a deep scour channel to the south. This channel is used by Interstate 84 and Portland's light-rail transit system. Terrace edges and approximate elevations are shown by hachured lines and large elevation figures. Surficial geology supports the geomorphic interpretation: Qal=Recent alluvial sand and silt; Qff=outburst-flood silt of late Pleistocene age; Qfc=outburst-flood gravel of late Pleistocene age; QTg=Pliocene-Pleistocene gravels; QTb=Pliocene-Pleistocene basaltic lava flows; Tt=Pliocene gravels; diagonal dashed lines indicate inferred buried faults. Modified from Allen (1979) and Madin (1989).

FIELD TRIP STOP 4. BONNEVILLE DAM

Finding an acceptable site for Bonneville Dam was exceedingly difficult. The geology of the Columbia Gorge at Bonneville is extremely complex, largely due to the results of volcanic activity, catastrophic ice age floods, and over 130 km^2 (50 mi^2) of landslides. The largest of the landslide debris flows, the Cascade slide, occurred approximately 700 years ago and covered an area of 50 km^2 (14 mi^2). Bonneville Dam is located on the toe of that landslide (Figure 7). Carbon (^{14}C) analyses of buried trees (Lawrence and Lawrence, 1958) indicate that the slide occurred around A.D. 1260. The temporary damming of the river that resulted was known in Native American legend as the "bridge of the gods." The remnants of the landslide toe formed the "cascades of the Columbia" until drowned by the water impounded behind the dam.

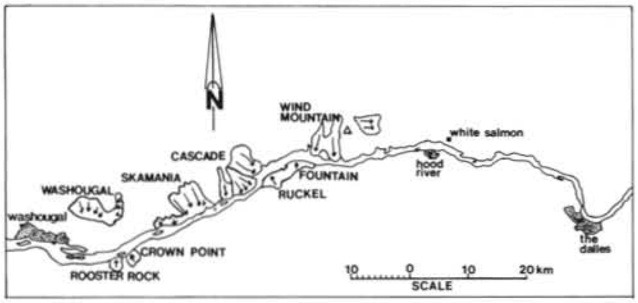


Figure 6. Major landslide areas between Washougal, Washington, and The Dalles, Oregon. Names of landslide areas are written in capital letters, names of cities in lower-case letters. Modified from Allen (1979).

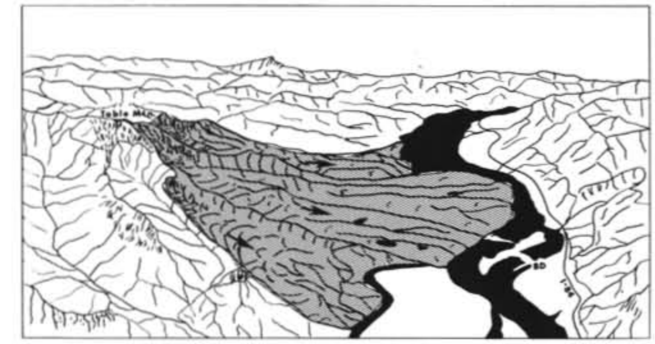


Figure 7. Oblique view of Cascade landslide zone, looking east. Arrows indicate three major slides within the zone. BD=location of Bonneville Dam. Sketch by Bret Hazell.

The Columbia River and its tributaries account for 40 percent of the hydropower potential of the United States. Bonneville Dam was the first dam built as part of the massive Columbia-Snake River development project. It is located 64 km (40 mi) east of Portland in one of the most scenic spots in the Pacific Northwest, the Columbia River Gorge. Its location places it at the tidal limit of the Columbia River, about 235 km (145 mi) from the Pacific Ocean. The dam impounds 77-km (48-mi)-long Lake Bonneville and incorporates a spillway, two powerhouses, three fish ladders, and a fish hatchery.

In 1930, engineers and geologists in search of a stable dam foundation were unable to find suitable bedrock through the Cascade slide). Additional core samples identified an acceptable site near Bonneville in November of 1933, and construction began immediately. However, after more drilling, geologists located a better site 2,000 ft downstream for the original site. Construction was moved to the dam's present location, where engineers found a good bedrock foundation for the dam in two basalt intrusions or uplifts.

Bonneville Dam is a key part of the government's multipurpose development of the Columbia-Snake River region. Its two powerhouses have a generating capacity of 1,084.3 Megawatts and are part of a vast hydropower system supplying 85 percent of the electricity for the Pacific Northwest. Bonneville Dam was constructed to provide hydropower and navigation but does not provide any flood control. Besides hydropower, dams on the Columbia-Snake system provide navigation, irrigation, recreation, fish and wildlife habitat, and crucial flood control.

Bonneville Fish Hatchery is operated by the Oregon Department of Fish and Wildlife and is the oldest hatchery in Oregon. The Bonneville Hatchery is just one of many in the Columbia system that together produce 150 million salmon and 9 million steelhead fingerlings each year. The hatchery is part of the most extensive fish preservation project in the world. In the past decade, over $1 billion was spent on improvement of fish runs or in revenue losses through reduced hydropower production.

The new Bonneville Navigation Lock is scheduled for completion in 1993 and will replace the original lock built in the mid-1930s. During an average year, 10 to 12 million tons of cargo, primarily grains and petroleum products, pass through the facility. The new lock, built at a cost of $329 million, will improve the average time in system for a barge from 12.7 hours to 1.9 hours.

Continue east on I-84 to Mosier, exit and turn east toward Rowena and Mayer State Park. Continue 14.5 km (9 mi) to the Tom McCall Memorial Grassland and overlook.

FIELD TRIP STOP 5. ROWENA OVERLOOK

The overlook is located at the entrance to the Columbia Gorge, where the waters of the Spokane floods washed over the valley walls to an elevation of 300 m (1,000 ft). The rocks have been stripped of soil, and the floodwater elevation can easily be seen on the opposite shore, where Columbia River basalt is exposed just east of Lyle, Washington. The Ortney anticline (east) and Mosier syncline (west) deform the basalts along this section.

Descend the Rowena loop eastbound and return to I-84 East. Continue to The Dalles. Exit I-84 at the Second Street exit, turn right on Liberty Street, climbing to the top of the hill, then turn left on The Dalles Scenic Drive. Stop at the Sorosis Park overlook.

FIELD TRIP STOP 6. THE DALLES

The city of The Dalles has had a long history of progressive landslide damage to structures and utilities due to slow-moving creep of a deep-seated slide (Beaulieu, 1985) (Figure 8). The upper surface at the overlook consists of the clay-rich Chenoweth Formation, which has been progressively sliding on top of the Columbia River basalt, which dips locally toward the river. The Spokane floods ponded here to depths of 300 m (1,000 ft) and almost certainly caused oversteepening and erosion of the lower slopes by removal of lateral support to the slope. As the city grew, local springs were blocked, buildings loaded the slope, and drainage was allowed to infiltrate into the slide mass. As a result, ground movement of 1.2-5.3 cm/yr have been recorded throughout much of the area.

Figure 8. Landslide area in The Dalles. Outlined arrows indicate damage to structures, streets, and utilities due to ground movement; solid arrows indicate recent slide activity. Stippled area shows most active "inner zone" of this nested slide block. Modified from Sholin (1982).

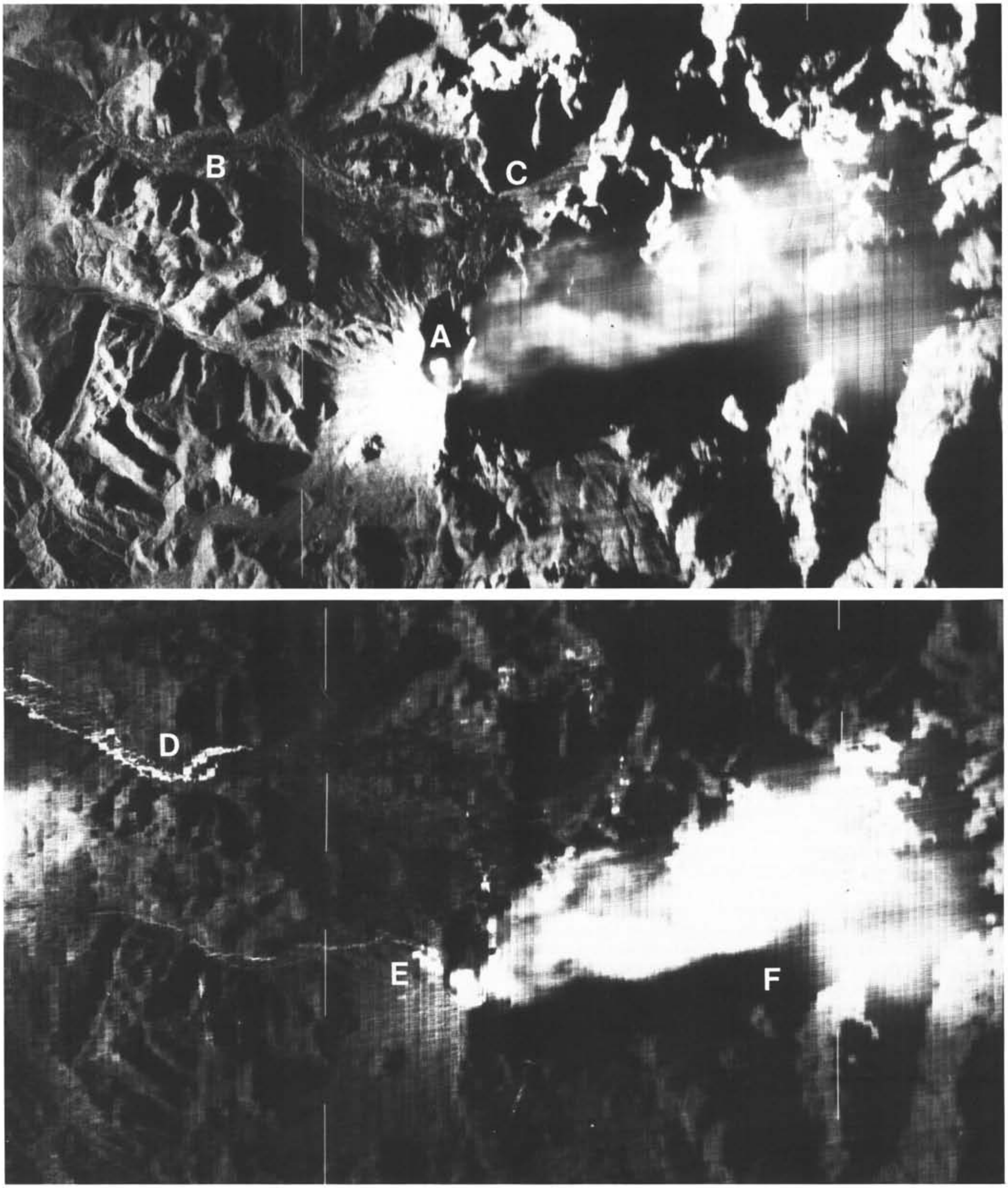


Figure 9. Side-looking airborne radar (SLAR) images of the May 18, 1980, eruption of Mount St. Helens. This technique was used to penetrate the heavy ash in the lower atmosphere. The image is divided into two channels: The top image illustrates stationary objects, such as the newly formed explosion crater (A), the hummocky surface of the debris avalanche (B), and the debris covering the surface of Spirit Lake (C).In the bottom picture, objects in motion are emphasized, such as the mudflows emanating from the terminus of the debris avalanche (D), a nuée ardente descending the west flank of the volcanic cone (E) and the debris-laden Plinian ash plume moving to the east of the volcano (F). The vertical dashed lines are 20 km (12.5 mi) apart. Imagery courtesy of Oregon Army National Guard.

Cross the Columbia River and return (west) to Carson, Washington, along Highway 14. Continue north to Swift Creek Reservoir and on to Mount St. Helens National Volcanic Monument and the Windy Ridge Viewpoint via Forest Service Roads 26 and 99.

VOLCANIC HAZARDS: THE MOUNT ST. HELENS EXAMPLE

The devastating eruption of Mount St. Helens on May 18, 1980, had a profound impact on the region. This formerly popular recreational area suffered complete destruction—with over 430 km^2 (166 mi^2) of forest destroyed and over 50 lives lost. But beyond the immediate destruction, the downwind ash fall, and the disruption of rivers by mudflows, the people of the Northwest were shocked into the realization that the volcanoes of the Cascade Range were much more than benign objects of beauty on the horizon. A heightened sensitivity to natural hazards has resulted from this dramatic event.

For scientists, Mount St. Helens, the youngest and most studied Cascade volcano, is an excellent natural laboratory. Many pioneering studies already underway at the time of the May 18, 1980, eruption have given us new insight to complex processes involved in an eruption, such as volcanic landslides, debris avalanches, lateral phreatic blasts, Plinian ash plumes, pyroclastic flows, lahars, and subsequent erosion and dissection of the landscape. The devastated landscape provides a rare opportunity for long-range geomorphic, hydrologic, and biological studies as it recovers from this catastrophic event.

During the last 4,500 years, Mount St. Helens has been more explosive than any other volcano in the conterminous United States (Crandell and Mullineaux, 1978). At the time when Mount Baker was showing increased thermal activity (Rosenfeld and Schlicker, 1976), Crandell and others (1975) warned that, based on past history, Mount St. Helens could erupt soon—possibly before the end of the century.

On March 15, 1980, the western Washington seismic network detected a series of small earthquakes beneath the volcano. Seismicity markedly increased on March 20, followed by a small phreatic eruption on March 27 that opened a small summit crater (Rosenfeld, 1980). The summit crater continued to enlarge for two months as phreatic (steam-blast) activity continued, eventually reaching 700 m (2,300 ft) in length and 200 m (656 ft) in depth. During this phase, viscous magma was intruding high into the older volcanic cone, inflating the northeast flank of the mountain and creating an ominous "bulge" beneath Forsyth Glacier. The inflation continued at a constant rate of 2.5 m (8 ft) per day with no acceleration until the cataclysmic eruption.

At 0832 local time on May 18, a Richter magnitude 5.1 earthquake triggered the failure of the unstable north slope in a landslide that was enhanced by the rapid unloading and depressurizing of the buried magmatic injecta and associated superheated ground water. The landslide and the debris subsequently produced by phreatic explosions formed a complex debris avalanche that descended the volcano's north flank and traveled 25 km (15 mi) west down the valley of the North Toutle River in about 10 minutes. Unloading by the landslide and rapid release of confining pressure on the superheated interior of the cone together produced a north-facing lateral explosion that carried pyroclastic debris outward, toppling trees over a 500-km^2 (193-mi^2) area and killing most living things with an air temperature of about 600°C (Rosenfeld, 1980).

The eruption eliminated the upper 400 m (1,300 ft) of the volcanic cone and excavated a 625-m (2,000-ft)-deep crater, 2.7 km (1.7 mi) long and 2.0 km (1.2 mi) wide, in the remaining mountain. About 30 minutes after the blast, lithic fragments were explosively ejected in an eruption column that reached 14-16 km (8.5-10 mi) in altitude throughout the morning. Around noon, a lighter colored and more energetic eruption plume (possibly as fresh supply of gas-rich magma reached the surface) attained an altitude of over 19 km (12 mi) and was carried as far east as Denver, Colorado. Also around noon, melting ice, and ground water began to coalesce in the 2.5-km^3 (0.6-mi^3) debris avalanche. As a result, saturated debris formed a lahar (volcanic mudflow) that descended down the North Fork Toutle River valley in to the Cowlitz and eventually the Columbia Rivers. This mudflow destroyed over 200 homes and deposited over 72 million m^3 (94 million yd^3 or 2.5 billion ft^3) of sediment along its course (Lipman and Mullineaux, 1981).

In addition to ground observations, remote sensing captured many of these events. Rosenfeld (1980) used side-looking airborne radar (SLAR) to penetrate the heavy ash concentrations in the lower atmosphere that obstructed most direct observations. Figure 9 shows many of the features described in the preceding text as they actually occurred.

FIELD TRIP STOP 7. WINDY RIDGE VIEWPOINT

The viewpoint is located 7 km (4.3 mi) northeast of the crater, along the divide between the Toutle River basin and the Lewis River basin. Windy Ridge is capped by about 1 m (3 ft) of blast deposits from the lateral blast. These deposits include gravel- to coarse-sand-sized rock fragments from the volcanic cone, including light-gray vesicular dacite from the "bulge" intrusions, and fragments of shredded wood.

From the crest of the ridge, north of the parking lot, the top of the 235-m (770-ft)-high dacite dome (extruded between 1980 and 1986) can be seen, as can the hummocky debris-avalanche deposits, the lighter toned pyroclastic flows, and Spirit Lake. Figure 10 shows a sketch of the panorama from this site. One can visualize the eruptive sequence: First the lateral blast surged over the landscape, shredding the forest and scouring up to 1 m (3 ft) of soil. The hot blast deposit then coated the landscape. The landslide/debris avalanche, moving at 250 km/h (155 mi/h), entered Spirit Lake and caused a catastrophic wave that washed northwards nearly 400 m (1,300 ft) up the flanks of Mount Margaret. Losing momentum, this wave sloshed back into the lake basin, washing many broken trees with it. Large blocks of the debris avalanche, some more than 20 m (65 ft) in diameter, came to rest in Bear Cove on the northwest shore of the lake, 10 km (6 mi) from the mountain. Another high-speed portion of the avalanche overtopped Johnston Ridge on the north side of the Toutle valley, as the remainder of this broken mass headed down the valley for an additional 20 km (12 mi).

The Spirit Lake basin collects runoff and snowmelt from the north flank of the volcano and its basin. Pumping was used to keep the lake from overtopping and possibly causing liquefaction or catastrophic erosion of the unstable debris-avalanche blockage. The pumps were replaced by a 2,500-m (8,200 ft)-long, gravity-fed

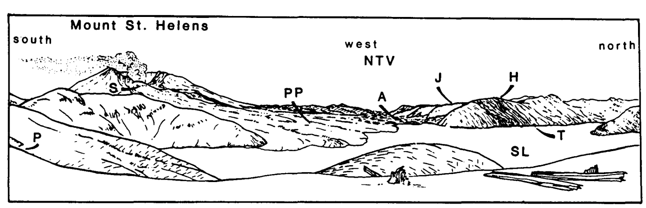


Figure 10. Panoramic sketch of the view to the west from the hill above the Windy Ridge parking lot. Volcanic gas and water vapor always rise from the dome. During humid weather, water vapor condenses to form visible plumes from dome and fumaroles in the pyroclastic flows of the Pumice Plain. P=Windy Ridge parking lot, J=Johnston Ridge, S=Sugar Bowl dome, H=Harry's Ridge, PP=Pumice Plain, SL=Spirit Lake, NTV=North Fork Toutle River valley, T=Spirit Lake outlet tunnel, A=debris-avalanche deposit (Spirit Lake blockage). Drawing by Bobbie Myers.

tunnel cut through Harry's Ridge to Coldwater Creek, thus fixing the water level in Spirit Lake.

A small instrument shed on Harry's Ridge houses measurement and telemetry equipment used by the U.S. Geological Survey to monitor volcanic activity. When significant changes occur, the Survey notifies the USDA Forest Service, the agency that is responsible for all access decisions within the Mount St. Helens Volcanic National Monument.

Return from Windy Ridge parking lot back to the Meta Lake turnoff (Road 26). Meta Lake is an excellent example of the blowdown area, and a point about 8 km (5 mi) north of Meta Lake shows the terminus of the lateral blast 18.7 km (11.6 mi) north of the crater. Continue north to Randle, Washington. Proceed west on Highway 12, then south on Route 505 towards Toutle, Washington. Turn east on Route 504 and proceed to the Toutle River Sediment Retention Structure.

FIELD TRIP STOP 8. TOUTLE RIVER SEDIMENT RETENTION STRUCTURE

This location demonstrates the geomorphic disruption of the landscape caused by the eruption. The immediate concern following the eruption was to assess the natural-hazard potential posed by outburst flooding from avalanche-dammed lakes, flooding, and renewed mudflow activity. Such outburst flooding could be caused by increased runoff and sediment constriction of the main channel. Initial assessment techniques included (1) interpretation of aerial photos of the impacted basins to determine the location and volume of deposits, detention ponds, and blockages to drainage, and (2) aerial surveillance by aerial photo radar and during periods of renewed volcanic activity to provide downstream warning in the event of resultant outburst-flooding or mudflow events (Rosenfeld and Cooke, 1982).

Following the rescue and recovery operation, scientists started numerous erosion monitoring activities within the devastated area, including placement of erosion stakes, measurements of sedimentation and discharge, and aerial photography after each storm.

The U.S. Army Corps of Engineers constructed the Sediment Retention Structure to inhibit the release of sediment from the upper Toutle River basin and reduce sediment constriction of the lower reaches of the Toutle, Cowlitz, and Columbia Rivers. A hasty retaining structure, N-1, was constructed on the North Fork Toutle River and completed by fall of 1980. Monitoring of sediment storage and periodic dredging of accumulated materials was planned for this structure.

Figure 11 summarizes the major components of the 1980-81 sediment budget as determined by the aerial inventory, field measurement of erosional processes, and periodic sampling of the stream. Various components of the landscape responded differently to episodes of volcanic activity, climatic events, and man-made erosion control and stabilization projects, and this has thwarted efforts to accurately model a long-term sediment budget for the area. However, several important process-response relationships have been accurately observed, and their trends can be identified.

The rockslide-debris avalanche deposits occupied a 35-km (22-mi)-long path from the breached northern face of Mount St. Helen, down the north flank of the cone, and filled more than 60 km^2 (23 mi^2) of the North Fork Toutle valley to depths ranging from 10 to 195 m (33-640 ft). The composition of this material averaged 45 percent gravel to boulders, 40 percent sand, and 15 percent silt, with coarse pumice resulting from successive pyroclastic flows overlying parts of the upper 5 km (3 mi) of the deposit. Erosion of the debris avalanche proceeded chiefly by the development of new channels and the extension, deepening, and widening of channels initiated by the floods and mudflows of May 18-19, 1980, and subsequent breaches and outburst floods from impounded tributary lakes and detention ponds. Channels and gullies range 3-50 m (9-164 ft) in depth and 3-200 m (9-650 ft) in width, with banks sloping from 30° to 70°. Bank undercutting during high flow periods causes slumping and bank recession, especially where the channel is braiding. Initial channel development was rapid, excavating over 43 million m^3 (1.5 billion ft^3 or 56 million yd^3) during the first year of post-eruption activity, an amount roughly equivalent to 2 percent of the total volume of the debris avalanche and more than half the total sediment yield for the basin. Continued mapping and measurements through October 1983 suggest that while wet-season channel network extension continues, it does so in response to specific volcanic or climatic events; furthermore, due to the hummocky nature of the debris surface, it does not develop a predictable pattern. A ten-year storm event is predicted to yield 8.78 million m^3 (35.3 million ft^3 or 100 million yd^3.

As several of the marginal lakes dammed by the debris avalanche have threatened to breach and cause outburst flooding, artificial spillways were constructed at Coldwater Lake and Castle Creek Lake. Continued volcanic activity through 1986 built a lava dome over 230 m (755 ft) above the crater floor. Character-

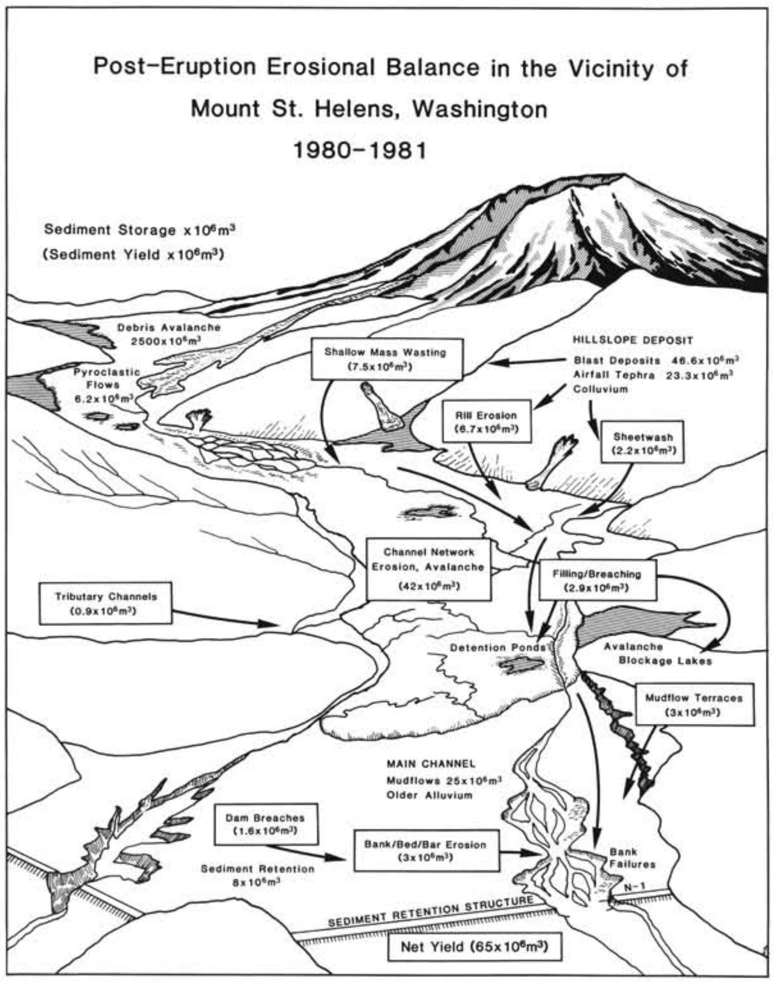


Figure 11. Schematic illustration of Mount St. Helens sediment budget. See discussion in text.

ized by pumice flows, lava extrusion and small, ash-laden explosions, several episodes have had substantial impact. For example, on March 19, 1982, a blast of hot pumice, dome rocks, and gas dislodged snow from the crater wall, triggering an avalanche of rock and ice that descended 8 km (5 mi) down the north flank of the mountain. A combination of frictional heat and warmth from the juvenile pumice caused rapid melting of the avalanche deposit, forming a transient lake within the crater with an estimated volume of 4 million m^3 (141 million ft^3 or 5.2 million yd^3. A flood of water and pumice simultaneously discharged both east and west of the lava dome, coalescing into a fluid lahar that cut a 30-m (98-ft)-deep channel while reaching an estimated discharge of 14,000 m^3 (494,000 ft^3 or 18,000 yd^3) per second. After descending the north flank of the volcano, the lahar divided into anastomosing channels across the surface of the 1980 debris flow, causing the integration of previously isolated basins into the channel network and incising certain channel segments more than 10 m (33 ft). Two lithologically distinct surges reached the N-1 retention dam 35 km (22 mi) from the crater, filling the basin with 1.9 million m^3 (67 million ft^3 or 2.5 million yd^3) of sediment, then breaching and severely eroding the structure. Below the spillway, the sediment aggraded into the main channel of the Toutle River, previously choked by deposition from the winter storms of 1981 and 1982. Although peak discharge was an order of magnitude less than the deluge of May 18, 1980, the mudlines of this event came within a few meters of the initial lahar. As long as Mount St. Helens remains volcanically active, a potential exists for additional destruction from floods and muddy lahars far from the vent.

Construction of the Toutle River Sediment Retention Structure (SRS), just upstream from the confluence of the Toutle and Green Rivers, was completed in 1989 at the cost of $73.2 million. Its design was based upon a worst-case scenario of an explosive volcanic eruption during a large winter snowpack. If such an event were to occur, models have predicted, a flow of 75 million yd^3 (57 m^3) of mud and debris would come down the North Fork Toutle River.

The SRS is designed to retain sediment and debris, not water. Its unique design consists of a 550-m (1,800-ft) embankment, a concrete outlet structure, and a 600-m (2,000-ft)-long spillway along the north side. The SRS embankment is primarily built of rock fill over a compacted alluvial foundation. Its design allows water to pass through filter zones both underneath and through the edifice. The huge concrete outlet structure has six rows of five outlet pipes allowing water and fish to plunge vertically into the downstream outlet basin. These pipes will be systematically closed as sediment accumulates on the upstream side of the structure.

It is estimated that the 1,300-ha (3,200-acre) lake behind the SRS will fill completely with 250 million m^3 (8.8 billion ft^3 or 327 million yd^3) of sediment and debris by the year 2010. SRS functions unmanned and is monitored by instruments for seepage, settlement, lateral deflection, internal pressure, and seismic movement.

When Hwy 504 is completed in summer of 1993, the debris avalanche will be open for visitors, who will be able to drive to Coldwater Lake within the National Monument.

Return along Highway 504 to Castle Rock. Be sure to stop at the Mount St. Helens visitors center to see the displays. Return to Portland via I-5 south.

FIELD TRIP STOP 9. COUNCIL CREST PARK, PORTLAND

Council Crest Park in the Portland Hills provides a good view of the metropolitan area, its terraced floodplain portions as well as the reminders of past volcanic activity, and, weather permitting, of the chain of the High Cascades. Among the geologic hazards of the area (Figure 12), one type is now receiving particular attention: the earthquake hazards.

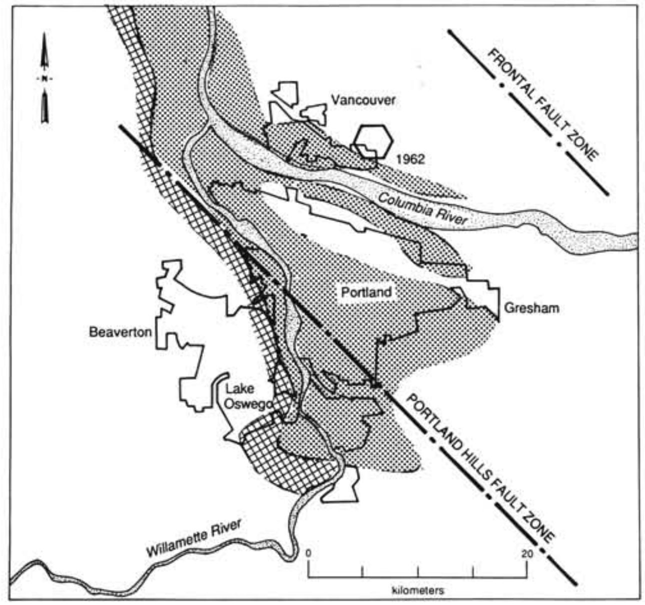


Figure 12. Portland area sketch map showing fault zones, areas of steep slopes (crosshatched), areas of unconsolidated sediments (dotted), and epicenter of 1962 earthquake (hexagon). Modified from Wong and others (1990).

Seismic risks in the Portland metropolitan area

The active subduction process along the Cascadia Subduction Zone implies several possible types of earthquakes in the Portland area: (a) Shallow crustal (upper plate) earthquakes, occurring along local faults and with potential magnitudes (M) up to M 7.0; (b) large, deep (intraplate) earthquakes, occurring within the subducted Juan de Fuca Plate, 40-60 km (25-37 mi) beneath the surface and with potential magnitudes up to M 7.5; or (c) very large (interplate or interface) earthquakes, occurring where the surfaces of the plates meet and periodically slip, with the potential of causing earthquakes of magnitudes M 8, 9, or greater (Figure 13).

All of the historical earthquakes have been the shallow crustal variety, the largest being a M-5.1 event centered on Vancouver. The current state of fault mapping and the short record of historical earthquakes make estimation of earthquake potential and magnitude difficult. Large, deep earthquakes, originating at depths of 40-60 km (25-37 mi) within the subducted Juan de Fuca Plate, have occurred in the Puget Sound region. The occurrence of a small number of well-located, similar earthquakes suggests that those seismogenic plate conditions also exist under northwestern and southwestern Oregon. Although it is easy to dismiss the seismic risk on historic

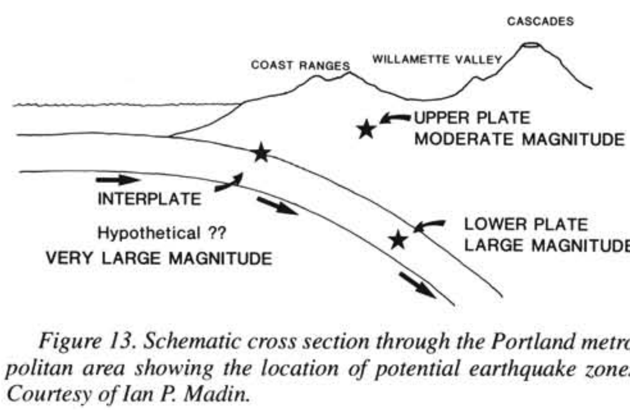


Figure 13. Schematic cross section through the Portland metropolitan area showing the location of potential earthquake zones. Courtesy of Ian P. Madin.

grounds, a growing body of geologic and seismic evidence suggests that a previously unrecognized level of earthquake hazard may exist in the Portland area.

In view of the lack of data for determining potential earthquake sources, efforts in Portland are focusing currently on characterizing the area's potential for disastrous responses to earthquakes, particularly amplified ground shaking and liquefaction. Soft or low-cohesion soils up to 50 m (164 ft) deep are widespread in the metropolitan area (Madin, 1989), and drilling is underway to map their location, character, and proximity to adjacent faults. The current mapping efforts will eventually lead to maps that can be used by government agencies, engineers, and planners for hazard mitigation.

Drive west on Highway 26 to Highway 6, continue toward Tillamook. Stop at Milepost 31.

FIELD TRIP STOP 10. WILSON RIVER LANDSLIDE

On April 4, 1991, a large planar slide occurred at this site, closing Highway 6 with an estimated 400,000 m^3 (14 billion ft^3 or 523,000 yd^3) of landslide debris (Figure 14). This type of mass wasting event is quite typical of large-scale landslides in the Coast Range. Precursors to this event were heavy saturation of the slope by a series of winter storms, tension cracking along the upper failure plane, which allowed rapid infiltration of surface runoff, and small mudslides of liquefied soils at the site immediately preceding the rapid failure of the slope.

The failure plane occurred along the contact of two deeply weathered basaltic breccia units at an average depth of 17 m (55 ft) at a 33° angle. The apparent "trigger" for this catastrophic failure was the increased loading and elevated pore-water pressure that resulted from abnormally high antecedent rainfall. The crest of the Coast Range received more than 150 mm (6 in) of precipitation in the preceding 24 hours and a total of 275 mm (8.8 in) over the preceding 30 hours. The slide blocked 200 m (650 ft) of the highway and partially obstructed the Wilson River. Removal and repair costs exceeded $2 million.

Figure 14. Wilson River canyon landslide of 1991. Photo courtesy of Susanne L. D'Agnese, Oregon State Highway Division.

Continue west, pass through Tillamook, turn south on Highway 101, and follow the Three Capes Scenic Loop to Netarts Bay Drive. Continue south on Netarts Bay Drive to Wee Willie's Restaurant.

FIELD TRIP STOP 11. SHORELINE SUBMERGENCE AT NETARTS BAY

Although western Oregon comprises about a third of the Cascadia Subduction Zone, it has not experienced a subduction earthquake in historic times (<200 years). This apparent lack of large-scale subduction may be attributed to aseismic slip of the subducting plate, terminated subduction, or intervals of periodic seismicity that are longer than the historic record. Recent large-scale subduction-zone seismicity (Chile, 1960; Alaska, 1964) have produced rapid coastal subsidence. From wetland burial sequences of Holocene age along the coast of Washington, Atwater (1987) has reported multiple events of abrupt coastal subsidence found by coring in protected bays. Peterson and others (1988) have located similar buried organic horizons in the protected environment of Netarts Bay. Using ^{14}C dating of the Holocene organic material to establish a chronology of multiple marsh burial events, they reasoned that rapid submergence is marked by burial of a peat layer that represents the drowned marsh vegetation. The peat horizons are covered, often in extremely abrupt transition, by a capping layer of sandy and silty sediments and then finer silts and bay sediments. Evidence in the capping sediment layer indicates turbulent sand deposition from a large-scale sheetflood that was possibly caused by a tsunami event. Many of the peat horizons contain freshwater diatoms indicating a high marsh setting, while the bay silts contain marine-brackish diatoms of subtidal origin.

Radiocarbon ages of the youngest buried peats come from borings in the mud flats at the south end of the bay and indicate an event 400 years B.P., clearly before the historical record. A total of seven marsh burial events are recorded in the upper 5 m (16 ft) below the present marsh, with ages ranging up to 3,300 years B.P.

The shortest duration in radiocarbon age between burial events was possibly less than 100 years, while the greatest interval is on the order of 1,000 years.

Longer records of Holocene marsh burials are needed to understand the tectonic cycles inferred from these data; however, some additional evidence indicates that subsidence of marshes in Netarts Bay can be traced back into late Pleistocene time in adjacent bay terrace deposits. At least two wetland forest horizons rooted in Pleistocene terrace material are similarly buried by bay muds. The magnitudes of coastal subsidence associated with the forest burials must certainly be greater than those that buried wetland marshes. The best exposure of these remnant forests may be seen at the tidal flats and terrace exposures just north of Wee Willie's Restaurant, near point T3 in Figure 15.

At low tide, numerous tree stumps are exposed in the modern tidal flat. Several of these stumps are close to the base of the terrace exposure. Trenching through the thin cover of modern muds reveals that these trunks are rooted in the Pleistocene terrace deposits. Additional tree roots can be seen protruding from an additional organic-rich layer about 1 m (3 ft) above the base of the terrace bluff. The probable age of the terrace deposits exceeds 83,000 years B.P. and hence precludes the use of ^{14}C dating to estimate the recurrence intervals. Figure 15 details the terrace exposures at three points in the vicinity of this stop.

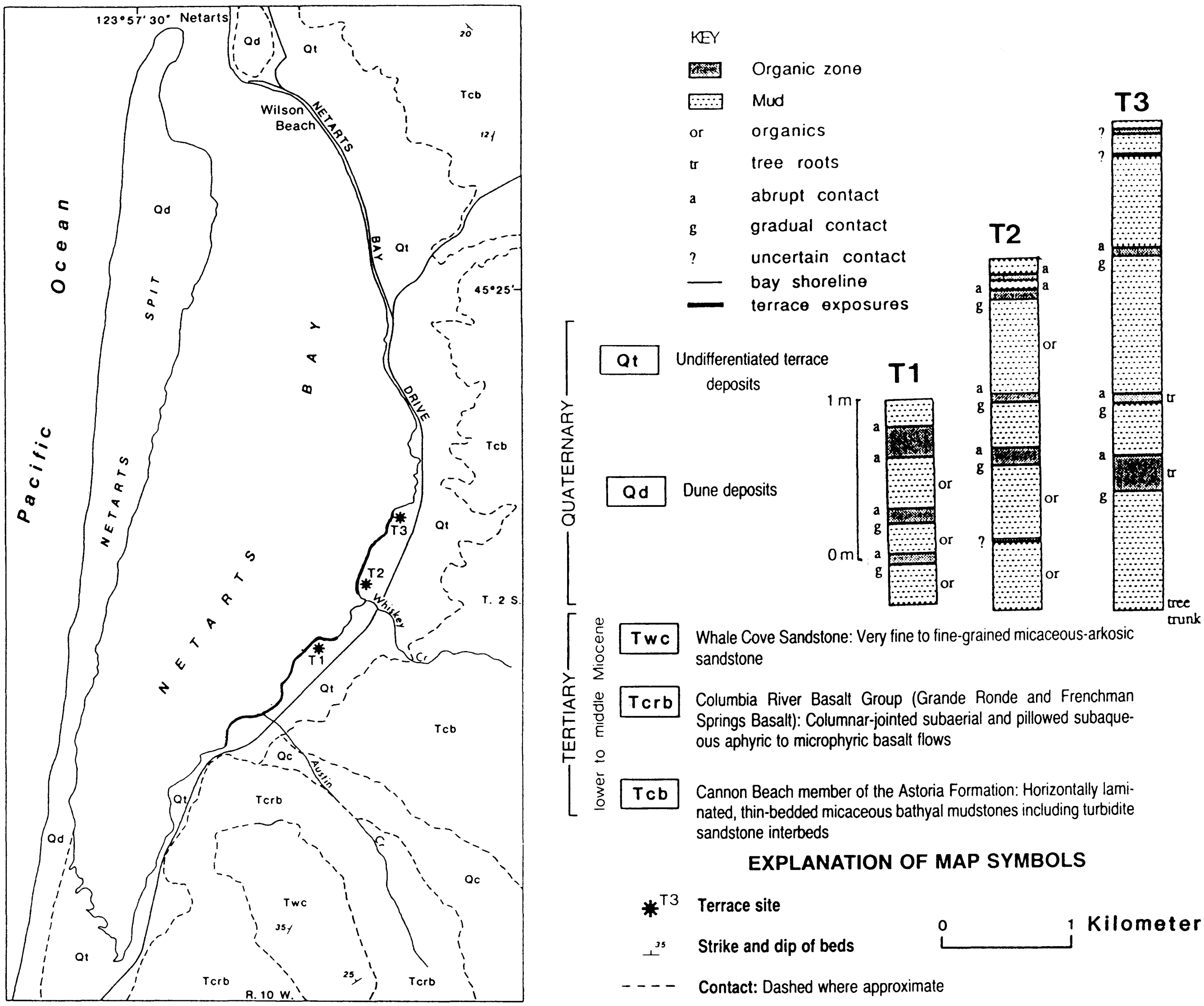


Figure 15. Netarts Bay area, late Pleistocene terraces, and stratigraphic sections of buried wetland horizons from the areas identified as T1, T2, and T3 on the map. Modified from Peterson and others (1988).

Return to Highway 101 and continue south to Waldport and Alsea Bay. Be sure to visit Alsea Bay Bridge Visitors Center for informative displays. Stop at Governor Patterson Memorial State Park south of the bay.

FIELD TRIP STOP 12. COASTAL EROSION AT ALSEA BAY

The threat of gradual sea-level rise over the next few decades poses an erosion hazard to much of the earth's inhabited coastline. A preview of such problems resulted from a brief rise of sea level related to the El Niño that lasted from April 1982 through July 1983, when a sea-level "bulge" was pushed northward along the west coast of the United States and, arriving at the Oregon coast during winter and spring, combined with an increased frequency of high-energy storm wave conditions.

The winter storms of 1982-83, accentuated by the El Niño, were a nightmare for the residents of Alsea Spit. The powerful northward longshore drift, accompanied by sediment from freshly eroded beaches and terrace deposits to the south, produced a massive sandbar along the south shore of the bay mouth. As a result, the discharge from the bay was effectively deflected northward and cut a channel close to shore along the distal tip of the spit. This allowed the big storm waves to attack the spit unimpeded by shallow-water shoaling (Jackson and Rosenfeld, 1987). The results were catastrophic: erosion was intense, rip-current creeps caused severe shoreline recession, and the spit was narrowed by 65 m (200 ft).

The northwest sea swells of summer gradually eliminated the bay mouth bar, but in doing so they exposed the tip of the spit to the southwest storms of winter. Between September and November 1985, over 120 m (400 ft) was lost to early winter storms. Figure 16 shows the position of the spit during December of 1978, 1983, 1985, and 1991. During the peak erosion winter of 1985-86, many of the homes on the tip of the spit were saved only by repeated placement of large basalt blocks or "rip-rap" along the shoreline. Vacant lots were permitted to erode. Since then, artificial backfills and natural reclamation have been used to rehabilitate the spit, and many previously eroded lots now contain new homes. Although the 1982-83 El Niño was arguably the strongest such event in this century— the actual change in sea level was an increase of about 50 cm (20 in.) over a five-week period. If predictions of future sea-level rise are accurate, significant shoreline change will certainly reach catastrophic proportions along the beach areas of the world.

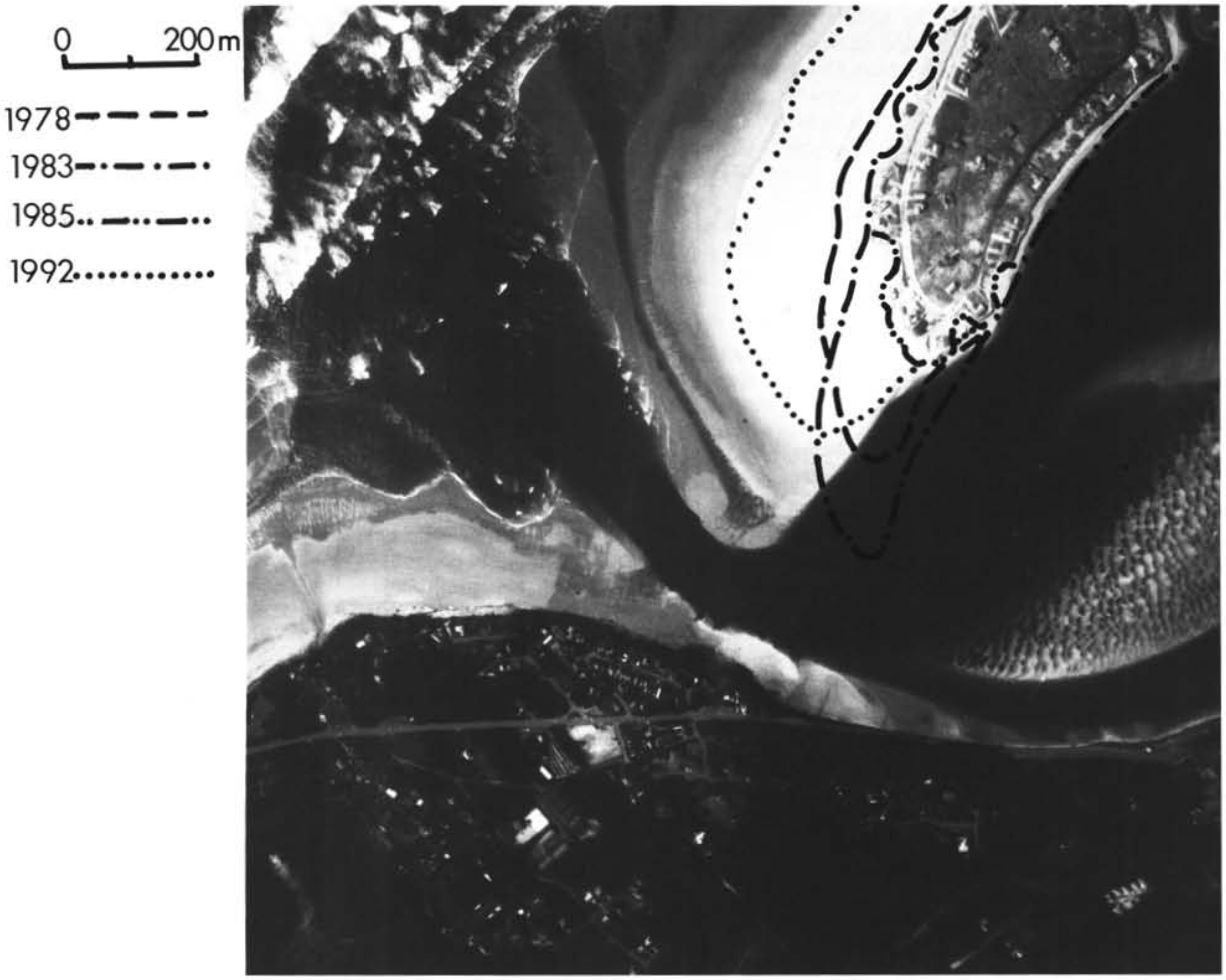


Figure 16. Shoreline changes at Alsea Bay, 1977-1991.

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Industrial minerals for environmental applications

by Ronald P. Geitgey, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97232

INTRODUCTION

Industrial minerals, the nonmetallic minerals, are the foundation of modern economies. They are the raw materials for the manufacturing, chemical, construction, and agricultural industries. Industrial minerals and their derived products are encountered daily in highways, glass, paper, fertilizers, toothpaste, plastics, cosmetics, table salt, and stonewashed jeans.

A perhaps lesser known field of industrial mineral use is the area of environmental protection and of mitigating environmental hazards. Mined materials remove, neutralize, or isolate various pollutants and reduce burdens on the environment by aiding energy and water conservation. The cleanup of massive oil spills and the bombing of forest fires with retardants are spectacular ways industrial minerals protect our environment, but most uses are far less conspicuous, such as insulation in homes and buildings, maintaining proper acid/base (pH) conditions in paper manufacturing and food processing, waste-water treatment, and drinking-water purification. Industrial minerals are used for environmental applications ranging from sealing waste disposal sites and removing sulfur dioxide from coal-fired power plants to smaller scale, more personal, protective uses such as sunscreen lotions and condoms. Some of the environmental applications are decades and even centuries old, others have been developed recently, and still others have been proven effective by laboratory testing but have not yet been developed into commercial products or processes.

This paper reviews a range of industrial minerals and their uses in environmental protection and in the conservation of various resources, which are ultimately means of minimizing environmental insult. A specific industrial mineral may have numerous applications, and a given use may employ various industrial minerals; thus, any discussion approach, from either the minerals or the uses, must involve some repetition. Figure 1 shows their major occurrences and producers in Oregon. Figure 2 shows the major connections between these minerals and their applications. The text lists the commodities in alphabetical order; no attempt has been made to rank the by volume used, market price, or any other means.

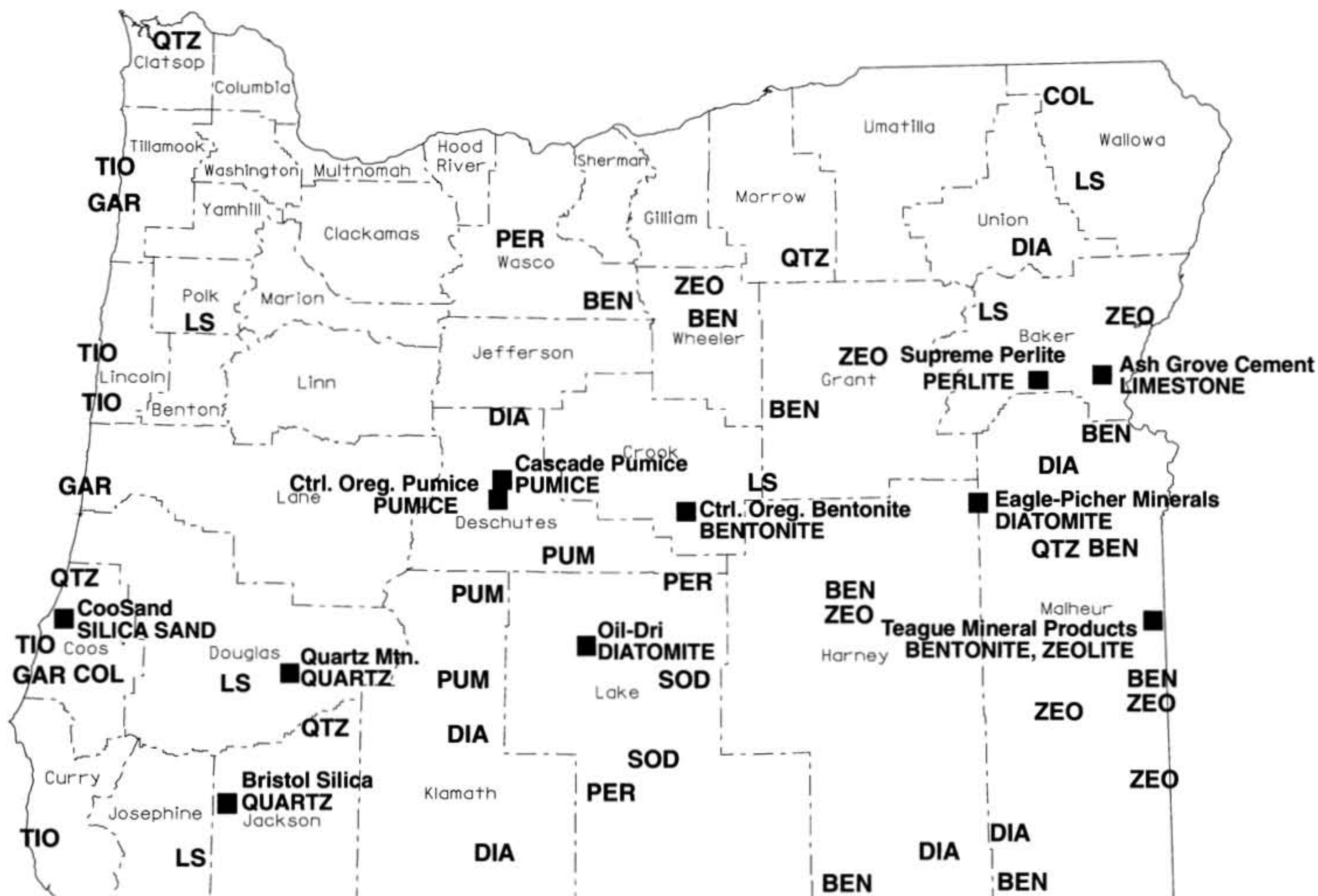

Figure 1. Producers and major occurrences in Oregon of industrial minerals with environmental applications. Producers and their products are approximately located by symbol and written out in full; other occurrences are identified by abbreviations: BEN=bentonite clay; COL=coal; DIA=diatomite; GAR=garnet in mineral sands; LS=limestone; PER=perlite; PUM=pumice; QTZ=quartz; SOD=sodium minerals from alkaline lakes and brines; TIO=titanium dioxide minerals; ZEO=zeolite, several different types.

BENTONITE CLAY

Bentonite is a type of sodium- and calcium-bearing clay that can absorb a large amount of water and swell to as much as 20 times its dry volume, forming a range of plastic solids, gels, or viscous fluids, depending on the amount of water present. It is formed by the natural alteration of beds of volcanic ash. The specific characteristics of bentonite can be modified by changing the proportions of sodium and calcium and by adding various organic polymers.

Historically, the largest use of bentonite has been in oil-, gas-, and water-well drilling, where it is circulated down the hole as a viscous mud to remove rock cuttings, cool the drill bit, prevent the hole wall from collapsing, and contain and control any fluids encountered. Increasing amounts of bentonite are being used in civil engineering—as a sealant and liner in ditches, ponds, reservoirs, building foundations, and waste disposal pits, often in conjunction with plastic liners. A small amount of bentonite mixed with soil in the pond or pit floor before it is filled swells when wet, forming a flexible, self-sealing barrier that can be tailored to specific requirements by adjustments in the amount and type of bentonite used. This barrier protects ground water against leachates from disposal sites and fluids from process pits and reduces losses from water reservoirs and irrigation ditches. Because of its high absorbency, bentonite is also used to clean up oil and gasoline spills and is a major component in many cat-litter products.

COAL

Nearly all coal is burned to produce heat, but a small amount is used as an industrial mineral in water filtration. As water flows through a bed of granular material, contaminant particles are trapped and filtered out. Smaller contaminant particles must be filtered out with smaller granules. Ideally, larger particles should be removed first to minimize clogging of the finer filter granules. A multilayered filter bed with coarser sand granules on top and finer sand granules on the bottom is a workable system—but difficult to clean without disturbing the layering. A layered and easily cleaned filter bed can be prepared with a bottom layer of fine garnet sand, a middle layer of medium-size quartz sand, and a top layer of coarse coal granules. Garnet is a heavy mineral, about four times as dense as water, quartz is about 2½ times as dense as water, and coal is only slightly heavier than water. These differences are the key to cleaning a used filter bed. Clean water pumped into the bottom of the bed stirs and mixes all the grains and flushes out the contaminant particles. When pumping is stopped, the heavy garnet sand settles to the bottom first, followed by the quartz sand, and finally the coal grains, reforming the layered filter bed.

DIATOMITE

Diatomite, or diatomaceous earth, is a powdery rock composed of the minute silica skeletons of aquatic plants that live in both marine and freshwater environments. Each skeleton is about the size of a dust particle and often resembles a finely filigreed or lacelike cage with elaborate holes and projections. This structure is a tiny sturdy sieve and a particle with very high absorbency. The filtration characteristics of each diatomite deposit vary with the species present and can be modified by heat treating. Numerous liquids are cleaned with diatomite filters for clarification, purification, and recycling. Drinking water, juices, beer, wine, vegetable oils, used motor oil, used dry-cleaning fluids, and sewage are a few examples.

Diatomite is highly absorbent and is used to clean up various liquid spills. Used by itself, diatomite can be an effective nonchemical insecticide, killing by laceration and desiccation. Insects secrete a waxy coating that prevents the loss of body fluids, but diatomite can absorb the wax faster than the insect can replace it. The sharp diatomite skeletons also work between the joints of the insect's exoskeleton, lacerating soft tissues and accelerating desiccation. Because of its absorbency, diatomite is also used as a slow-release carrier for chemical and biological insecticides such as the pyrethrins that would otherwise dissipate rapidly. The insecticides then last longer and can be applied at lower dosages.

GARNET

Garnets are a group of heavy, hard, and tough minerals that occur in various metamorphic rocks, as well as in mineral sands. The use of garnet in water-filtration systems was described above. However, the major use of garnet is as an abrasive, both on paper- and cloth-backed sheets and as air-blast abrasives (for "sand blasting"). It is in this latter application that garnet offers environmental advantages over quartz sand. Inhalation of quartz dust can cause a fatal disease, silicosis. Garnet does not present this hazard, and since it is harder and more durable than quartz, it can be reclaimed and reused repeatedly.

LIMESTONE

Limestone, calcium carbonate, typically occurs as a bedded deposit associated with other marine sediments. Roasting limestone at high temperatures produces lime (calcium oxide) and carbon dioxide. Limestone slowly dissolves in water, producing a weakly alkaline solution, while lime dissolves quickly producing a strongly alkaline solution. Both limestone and lime have long been used to neutralize acidic solutions and environments to maintain specific pH conditions for various processes. Examples include paper production, water treatment, waste-stream treatment, and neutralization of acid soil conditions to increase crop yields.

In recent years, processes have been developed to use limestone and lime in flue gas desulfurization, the removal of sulfur dioxide from the flue gases of coal-burning electric generating plants. Sulfur dioxide is a major component of acid rain. Much of the sulfur in coal, such as the iron sulfide minerals pyrite and marcasite, can be removed by various processing methods, but enough remains to form large amounts of sulfur dioxide when the coal is burned. Limestone or lime injected into the burners combines with the sulfur dioxide to form calcium sulfate, or gypsum, which is used to a limited extent in traditional gypsum markets. The United States has very large reserves of sulfur-bearing coal, and clean-air standards require increasingly lower sulfur dioxide emissions.

PERLITE

Perlite is glassy volcanic rock similar to obsidian but with about 2 to 5 percent water in its structure. Under proper heating conditions the glass softens, and the water turns to steam, causing the perlite to expand or pop, much like popcorn. The end result is a particle that is composed of tiny glass-walled bubbles, very light in weight, noncombustible, and with excellent insulating properties. Expanded perlite is used as loose fill insulation and as an insulating aggregate in concrete and in plaster products such as wallboard and ceiling tile. Milling, by grinding or crushing expanded perlite, produces material used for filter applications similar to diatomite. The most readily recognizable use of perlite is made in the form of the white beads added as an amendment in potting soil mixes to improve soil texture and aeration.

PUMICE

Pumice is a frothy volcanic rock that is often light enough to float on water. Its cellular structure, light weight, and relatively high crushing strength contribute to its use as a lightweight aggregate in cast concrete and concrete blocks. Using lightweight concrete can considerably reduce the total amount of structural material required in a building, and its insulating qualities reduce energy requirements for heating and cooling. Pumice is also used as a decorative ground cover in landscaping—to reduce or eliminate areas with plants that would require irrigation.

QUARTZ

Quartz, or silica, is one of the most common minerals in and on the Earth's crust. It occurs as veins and massive quartzite bodies as

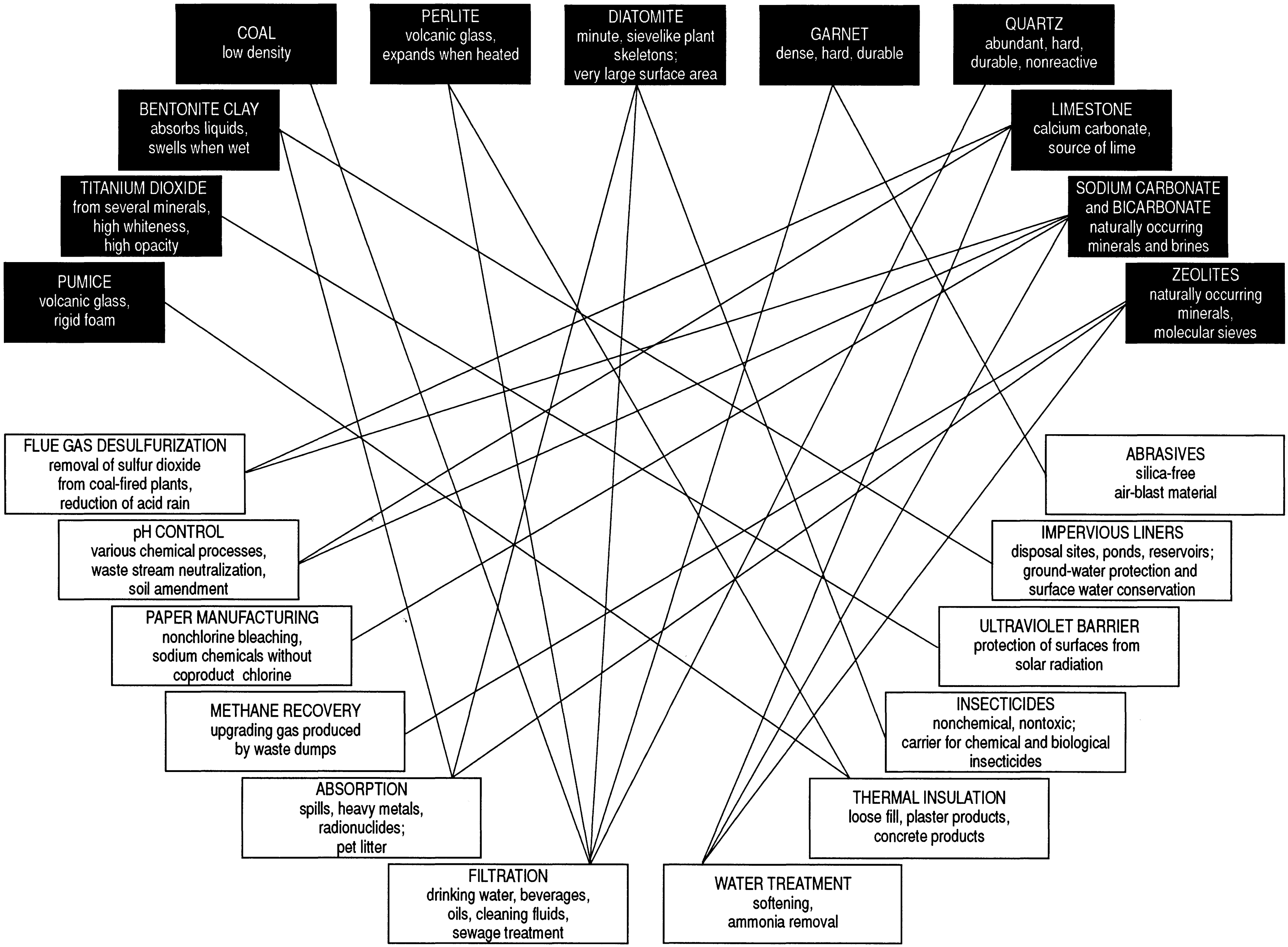

Figure 2. Examples of industrial minerals (top, shaded) used in environmental protection and resource conservation (bottom).

well as in sandstones, sand dunes, and beaches. Its principal use is in the manufacture of glass products. Quartz, both crushed and as sand, is widely used in filtration systems, where its durability and relatively low cost are major assets. Very finely ground or chemically precipitated silica is used as a filler in many plastic, rubber, and latex products—both to reduce the amount of more expensive chemicals required and to impart strength and durability. It is the presence of silica that so quickly dulls scissors used to cut plastic sheeting.

SODIUM CARBONATE

Sodium carbonate and sodium bicarbonate can be mined from bedded deposits, extracted from alkali brines, or manufactured from limestone and salt by the Solvay process. The Solvay process is very energy-intensive and produces a coproduct, chlorine, that must be marketed or otherwise disposed of. Since the United States has extensive bedded deposits as well as alkali lakes, the Solvay process is no longer used in this country.

Two major concerns of environmental protection offer a growing market for sodium carbonate and bicarbonate: flue gas desulfurization and paper manufacturing. For flue gas desulfurization, although the processes differ in specific details, sodium carbonate and bicarbonate are used in coal-fired burners in a manner similar to the use of limestone and lime. The resulting product, however, is sodium sulfate, which is a more marketable product than the limestone/lime product calcium sulfate. All four systems differ in capital and operating costs, and the one chosen for a specific plant must represent the economic and ecological optimum for that location.

Sodium chemicals are necessary for various processes in paper manufacturing. Historically, these chemicals were produced from salt (sodium chloride), and the unavoidable coproduct chlorine was used to bleach the paper as well as to produce plastics and other chemicals. However, various chemical reactions involving chlorine can generate the highly toxic dioxin family of compounds—and we know today of strong environmental reasons for reducing or eliminating dioxin production. Bleached paper can be produced without the use of chlorine; in fact, some sodium chemicals themselves can aid in bleaching. Producing sodium carbonate and bicarbonate from sodium mines and alkali brines rather than from salt avoids the generation of the coproduct chlorine, and so the use of these sources is increasing.

TITANIUM DIOXIDE

Several minerals contain titanium dioxide in sufficient quantity for commercial extraction. All these minerals are dark, hard, and chemically resistant, and these qualities make them occur commonly in black sands or mineral sands. Although these sands are a source for titanium metal as well, only about 5 percent of the production from sands is used for metal; 95 percent is used to produce titanium dioxide, a brilliantly white powder that is highly opaque to both visible and ultraviolet light. Its primary use is as an opacifying agent in paper, paints, and plastics, where it reduces the total volume of material required to produce an opaque sheet or coating. One of its conspicuous uses (or perhaps inconspicuous) is in typewriter correction fluid. The opacity of titanium dioxide to ultraviolet radiation reduces the deterioration by sunlight in paints and plastics and makes it an essential component of some sunscreen lotions.

ZEOLITES

The zeolites are a group of minerals characterized by a cagelike structure, with holes and passages whose dimensions are specific to each mineral. Zeolites readily exchange atoms (such as sodium, potassium, and calcium) in their structures for other atoms in contact with them in gases or in solution. They can also absorb gas molecules within their framework structures. Which atoms or molecules can be exchanged or absorbed is a function of their size and the size of the openings in the zeolite structure. For this reason, both naturally occurring and synthetic zeolites are referred to and function as molecular sieves. Early water-softener systems used natural zeolites to exchange sodium in their structure for calcium in hard water. Synthetic equivalents are now used. When the zeolite is fully loaded with calcium, a sodium chloride solution is flushed through the system to remove the calcium and recharge the zeolite with sodium. Synthetic zeolites that remove calcium from water are also used to replace the phosphate that is used for the same purpose in detergents.

Natural zeolites often occur as exquisite crystal clusters and fillings in the holes in lavas. However, the zeolites mined commercially occur as bedded deposits of altered volcanic ash. The properties of natural zeolites have been studied for decades, but in spite of their demonstrable utility and even occasionally exotic applications, very few deposits have been developed commercially, and the total market for natural zeolites remains small. This is due in part to the fact that synthetic zeolites can be manufactured to perform very specific tasks, although at much higher cost than natural zeolites, and in part because large-scale demand for some of the capabilities of natural zeolites has not yet developed. Considering their numerous potential applications in environmental protection, a growth in demand may not be far in the future.

Some zeolites selectively absorb nitrogen, others oxygen. An air stream passed through an appropriate zeolite bed can then be enriched in one and the zeolite in the other. This can provide a low-cost source of nitrogen gas for inert gas applications or oxygen for applications ranging from steel furnaces and sewage treatment to portable personal respirator units. A zeolite that absorbs methane is used to enrich to commercial quality the gas collected from covered solid-waste disposal sites. A zeolite that readily absorbs odors, particularly ammonia, is used in several commercial products including deodorizers for shoes, pet litter, and animal stables.

Natural zeolites can also absorb ammonia from water solutions and have been used in water-treatment systems for drinking water and aquariums and aquaculture ponds. This ammonia-absorption capability has also been beneficial in animal feed. The rate of weight gain in certain farm animals is in part dependent on the residence time of ammonia in their intestinal tracts. Zeolite in animal feed absorbs ammonia produced in the gut, slows its loss, leads to more rapid weight gains, and reduces odors at the conclusion of the process. Large volumes of zeolite could be used in feed and as treatment for feedlots and animal buildings.

Zeolites can be impregnated with fertilizers such as potash and nitrogen and then used as slow-release dispensers. Fertilizer application rates can be reduced, since the zeolites keep the nutrients in the root zone, and leaching is reduced—which both benefits the plant and decreases effluent from the fields, particularly in areas of sandy soils. Some natural zeolites selectively absorb heavy metals such as lead and zinc, and laboratory-scale experiments have demonstrated their effectiveness in reducing the heavy-metal content in mine drainage waters and reducing their availability to plants in contaminated soils.

Certain radionuclides are also absorbed and isolated by natural zeolites. Experiments in soils contaminated with radioactive cesium have shown that zeolite can markedly reduce uptake of cesium by food plants. Zeolites may also be useful in reducing the migration of radionuclides from waste disposal sites and from both contaminated surface sites and ground water.

CONCLUSION

All of the industrial rocks and minerals described above occur in Oregon. Some are currently produced for various end uses, including environmental applications; others, including bentonite and zeolite, are mined specifically for environmental-protection markets, and still others are not yet explored or developed.

Environmental protection and environmental cleanup are increasingly necessary activities. As standards are raised and stricter regulations are enacted, certain industrial minerals must be mined in greater volumes to both minimize environmental degradation and mitigate existing hazards. As with all natural-resource-based industries, the social and economic benefits of mining any commodity must be weighed in part against its environmental cost. The environmental costs of mining minerals for environmental protection must be viewed in terms of their environmental benefits.

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IN MEMORIAM

Harold J. Buddenhagen (1903-1991)

By Parke D. Snavely, Jr., Menlo Park, California, and Grant M. Valentine, Olympia, Washington

Harold Johnson "Bud" Buddenhagen passed away on November 3, 1991, at his ranch on Murphy Creek Road in southwestern Oregon.

Bud was born August 23, 1903, in Springfield, Illinois. He married the former Pearl (Pat) Marie Masteller of Selby, South Dakota, on March 15, 1928, in Hollywood, California. After graduating from Stanford University, he joined Shell Oil Company in 1926 as a petroleum geologist. He worked for Shell for 29 years in various western states, as well as in Venezuela for three years, and in the Netherlands at Shell headquarters in the Hague for 17 months.

After his retirement from Shell Oil Company in 1955, Bud and his family lived on Murphy Creek Road in southwestern Oregon on a ranch he and Pat had purchased in 1938. During 1970 and 1971, he and Pat traveled in a Volkswagen bus throughout Europe, the former Soviet Union, and Africa. Working out of the ranch, Bud consulted nationally and internationally for several major oil companies. He also was employed part-time with the Oregon Department of Geology and Mineral Industries to map the structurally complex geology of the John Day uplift in east-central Oregon. Bud relished this challenging assignment because it provided him an opportunity to apply his considerable expertise to unravel the tectonic and stratigraphic framework of this poorly exposed, faulted, and folded terrane that involves rocks ranging in age from Devonian to Cretaceous. Bud's geologic maps of this complex terrane are exceptionally detailed, with stratigraphic sections provided for each well-exposed outcrop. To constrain his formational contacts in areas covered by screens of colluvium, he enlisted the aid of his sons, John and James, to dig holes to the bedrock. In a 1967 report, Bud briefly described the lithostratigraphic units in the John Day uplift and stated that "deciphering the geology of this Paleozoic area is akin to working a jigsaw puzzle with many of the pieces missing." Despite constraints of poor exposures, faulted contacts, and chaotically intermixed volcanic and sedimentary rocks, Bud produced his exceedingly detailed geologic map of the Suplee-Izee area. This map was included in the compilation of the new geologic map of Oregon, filling a significant void in our knowledge of the geologic framework of east-central Oregon. Drafted copies of the geologic maps are kept at the Oregon Department of Geology and Mineral Industries in Portland, Oregon.

Bud's love affair with nature and geology found a common ground on his ranch along Murphy Creek on the north side of the Siskiyou Mountains of southwestern Oregon. For his last 35 years, he was fortunate to live with his beloved wife, Pat, in this forest-covered countryside that he enjoyed so much. Bud is survived by his wife; a daughter, Barbara Winkelstein of San Francisco, California; three sons, Ivan of Davis, California; John of Alcan, Alaska; and James of University city, Missouri; his dear sister, Kathryn Wilson of Oakland, California; and 15 grandchildren and one great-grandson, who added much joy to his life.

Harold Buddenhagen will be remembered by his friends here and abroad for his steadfast dedication to the geologic profession, his independent attitude and contagious sense of humor, and his unwavering pursuit of excellence. He was a member of the American Association of Petroleum Geologists and the Geological Society of America.

Bud's family and friends suggest a memorial contribution be made to the American Cancer Society.

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AAPG Bulletin, *v. 76, no. 5., p. 758-759.*

THESIS ABSTRACTS

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

Subsurface and geochemical stratigraphy of northwestern Oregon, by Olga B. Lira (M.S., Portland State University, 1990), 97 p.

Lithological, geophysical, paleontological, and geochemical methods were used in order to define the contact relationship between the Keasey and Cowlitz Formations in northwestern Oregon. Drill cuttings from six wells located in Columbia County were analyzed by the Instrumental Neutron Activation Analysis (INAA) method. The concentrations of K, Th, Rb, and the Sc/Co ratio in the samples established four different groups: (1) High K, Rb, and Th, with low Sc/Co ratio, typical of Cowlitz sediments. (2) Low K, Th, and Rb and high Sc/Co ratio, more characteristic of the Keasey Formation. (3) Very low concentrations of Rb and high Sc, which is indicative of basaltic volcanism. (4) Vertically varying K, Th, and Rb concentrations. The provenance of group four is uncertain, but it may represent reworked sediments or the interfingering of the Keasey and Cowlitz Formations. Plots of these elements vs. depth define the geochemical contacts between the formations.

The contact was also determined by interpretations of geophysical logs, the gamma ray log being the most useful. This log responds to chemical differences between the Cowlitz and Keasey Formations or local volcanic sediments. The apparent interfingering of the two formations is observed in wells drilled off the Nehalem arch. In the upper part of the arch, the Cowlitz Formation has been eroded. Therefore, the contact between the Cowlitz and Keasey Formations can be defined as conformable where they apparently interfinger and as unconformable where erosion or nondeposition is evident.

The contact between the Keasey and Cowlitz Formations, as interpreted from the geochemical data and gamma ray logs, is the same, and both data sets seem to reflect a lithologic break. However, the paleontological time boundary between the Refugian and Narizian stages does not in all the wells coincide with the formational boundary but occurs within the Keasey Formation. Therefore, Keasey Formation was deposited during both Narizian and Refugian time. In localities where the geochemical, paleontological, and lithological contacts coincide an unconformity is defined.

Late Quaternary tectonic development of the northwestern part of the Summer Lake Basin, south-central Oregon, by Gary D. Simpson (M.S., Humboldt State University, 1990), 121 p.

The Summer Lake basin is an extensional graben forming in the High Lava Plains of south-central Oregon, along the northwestern boundary of the Basin-and-Range province. The basin was occupied in the Pleistocene by pluvial Lake Chewaucan. Structure of the northwestern part of the basin is defined by three distinct fault sets: northwest-trending faults, the Winter Rim fault system, and a set of arcuate offsets within the volcanic highlands immediately north of the Summer Lake basin.

Cross-cutting relations with the other fault sets suggest that the northwest-trending faults are the oldest faults in the region. Available relations with Quaternary deposits demonstrate that these faults are largely inactive.

The Winter Rim system is defined by the main east-facing escarpment that forms Winter Rim and by numerous scarps at the base of the rim (Jacks Lakes, Summer Lake, and White Rock segments). The White Rock segment of the Winter Rim system offsets late Pleistocene or Holocene alluvial deposits and forms a strong photo lineament with the Jacks Lakes segment. The Jacks Lakes fault offsets shallow lacustrine deposits.

Stratigraphy in a fault-bounded depression within the arcuate pattern north of the Summer Lake basin suggests that sedimentation (and therefore development of the arcuate complex) was initiated between approximately 60 and 120 ka. Block reconstruction across this arcuate system suggests that the faults formed in a setting analogous to the head scarp of a landslide, as individual blocks of the Picture Rock basalt slid or toppled toward the encroaching extensional graben (i.e., the Summer Lake basin). These blocks may be sliding along a relatively shallow porous tuff layer.

Sediments within the northwestern part of the Summer Lake basin were extensively deformed 12-19 ka. Compressional folding and thrust faulting of the lacustrine sediments indicate a widespread compressional stress event that affected post-19 ka strata while the sediments were under saturated conditions. Because Lake Chewaucan presumably dried up about 12 ka, the age of the deformational episode must have occurred between 12 and 19 ka. Deformation occurs in localized areas as small- to large-scale isoclinal (often recumbent) folds and thrust features. Deformation often occurs along discrete bedding planes, often overlying (or sandwiched between) undeformed layers. Silt layers typically responded in a fluid, ductile manner, while intercalated tephra layers behaved plastically or brittlely.

Recent compression of valley fill sediments in a predominantly extensional environment is difficult to explain. Attitudes of exposed structures suggest that the compressive stresses may have been generated along the northern Winter Rim range front. Soft-sediment deformation resulting from a faulting event of the northern Winter Rim range front may be the mechanism that displaced the saturated sediments in the northwestern part of the basin. In any case, the sediments, which had remained submerged for over 300,000 years, were uplifted wihtin the past 19,000 years and exposed to weathering and dissection by the Ana River.

The petrologic evolution of the Holocene magmatic system of Newberry volcano, central Oregon, by Scott R. Linneman (Ph.D., University of Wyoming, 1990), 293 p.

This study tests the hypothesis that the bimodal basalt-rhyolite Newberry volcanic suite of central Oregon was formed by a combination of repeated, small-volume, mafic magma injections into the crust and by subsequent crustal partial melting. During the Holocene at Newberry, basaltic andesite lavas were erupted on the flanks, whereas rhyolitic tephras and lavas were erupted within the summit caldera. No simple model of fractional crystallization, single-component assimilation, or two-component mixing can account for the chemical variations observed in the Holocene mafic lavas. Rather, the data require that at least two very different components were assimilated by the parental basaltic andesite. The linear compositional trends were produced by assimilation of silicic material, either evolved crust or rhyolitic liquid. The isotopic characteristics of the suite were strongly influenced by a Sr-rich, radiogenic component, possibly a local sediment. The Holocene mafic lavas reflect the compositional variety of the upper crustal lithologies at Newberry.

Petrologic details from the Holcene rhyolites provide a compelling case for the existence, during the Holocene, of small, short-lived, possibly unconnected reservoirs of silicic crustal melts. These include (1) the lack of temporal correlations of geochemical variables, (2) possible geographic correlations of geochemical and isotopic variables, (3) physical evidence of crustal melting, (4) the lack of evidence connecting bimodal end members, and (5) evidence that the rhyolitic liquid(s) were superheated.

Physical evidence for a complex scenario of assimilation occurs within the Holocene lavas as mingled lavas and magmatic inclusions. The textural features and mineral compositions of the mingled lavas indicate xenocryst formation by (1) shear-induced folding of the silicic portion into the mafic portion and (2) mafic magmatic inclusion formation and subsequent disaggregation. The characteristics of the mafic magmatic inclusions of the caldera rhyolites can be explained by the mechanical disaggregation of larger, semi-rigid inclusions trapped in the BOF rhyolitic magma. Therefore, the coarse-grained inclusions are not petrologically significant cumulates.

Newberry volcano of central Oregon and Medicine Lake volcano of northern California have remarkable similarities, which suggests that the dominant petrologic processes acting at the two volcanoes are the same. Primitive high-alumina basalt is allowed into the upper crust by frequent episodes of extension associated with the volcanoes' location behind the Cascade volcanic arc. As an alternative to the widely accepted model of single, large, long-lived magma chambers, I propose that bimodal igneous suites are produced by repeated injection of small volumes of mafic magma into the crust. These small-volume bodies cause localized partial melting of the crust. In this manner, silicic magmas are generated in a series of small, nonconnected reservoirs. Evolved lavas erupted within a given volcanic system over a short time period may, therefore, be related only by their common anatectic origin, and their compositional and isotopic characteristics reflect preexisting crustal variability. □

AGI offers book on field safety

The American Geological Institute (AGI) has published a new book on safety for field geologists, campers, hikers—anybody who needs familiarity with the hazards of the outdoors and information about how to be prepared for and face these hazards.

Planning for Field Safety, AGI publication item no. 308, ISBN 0-913312-93-2, 197 p., soft cover, $14.95 plus $4.00 shipping and handling charges. Volume discounts are available for 10 or more copies. Orders may be mailed to AGI Publications Center, P.O. Box 205, Annapolis Junction, Maryland 20701, or phoned to (301) 953-1744.

The book will also be sold at the Nature of Oregon Information Center of the Oregon Department of Geology and Mineral Industries in Portland. See the ordering information on the back cover of this issue.

Planning for Field Safety describes hazards and pitfalls one may encounter in the field, suggests ways to avoid them, and tells what to do if they occur. It does so in well-organized, mostly brief sections and subsections (including some checklists), so that it is easy to find items even without the help of the very useful index at the end.

The introduction's announcement to deal with "the more common" hazards is somewhat of an understatement. The ten chapters cover a considerable range: from planning before the trip (e.g., weather, equipment, medicine, food, regulations for employees) to field risks (e.g., marijuana growers, contaminated food, pack animals, oceanic research vessels, thunderstorms, bears, spiders, poisonous plants), to particular regions (e.g., urban environment, high altitudes, tundra, tropics, caves, foreign countries) to emergency and evacuation procedures, instructions to group leaders, and how to ship rock samples. An appendix listing sources of information includes both printed materials and addresses of important agencies and organizations.

Even the brief description in the preface of how this book came into existence is impressive. □

New publications from DOGAMI describe geology of part of Jackson County and northwestern Oregon to margin of continent

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released two new publications: a quadrangle map for a part of Jackson County and a cross section for a strip of land extending west from Columbia County to the continental margin offshore.

Geology and Mineral Resources Map of the Boswell Mountain Quadrangle, Jackson County, Oregon, by Thomas J. Wiley and Frank R. Hladky. DOGAMI Geological Map Series GMS-70, one full-color geologic map, scale 1:24,000, one separate sheet with geochemical data. Price $7.

The Boswell Mountain quadrangle is located north of Medford and covers a region with a history of significant mining activity. It contains areas with some of Oregon's oldest rocks (more than 145 million years) as well as the western edge of the Western Cascade Range.

The geologic map is accompanied by a geologic cross section and brief discussions of geologic history and mineral and water resources. A separate sheet contains four tables listing geochemical data.

This map is the first of a series of maps planned to provide hazard and mineral-resource data as well as bedrock geology to aid regional planning in the Medford-Ashland area, which is experiencing rapid population growth. Two more quadrangle maps, Cleveland Ridge and Shady Cove, are nearing completion and are available for inspection at the DOGAMI field office in Grants Pass (5375 Monument Drive, phone (503) 476-2496).

Onshore-Offshore Geologic Cross Section, Northern Oregon Coast Range to Continental Slope, by A.R. Niem, N.S. MacLeod, P.D. Snavely, Jr., D. Huggins, J.D. Fortier, H.J. Meyer, A. Seeling, and W.A. Niem. DOGAMI Special Paper 26, 10 pages, one plate, geology at scale 1:100,000. Price $11.

The geologic cross section is constructed along a line that begins in Columbia County, crosses the Coast Range, and extends offshore across the continental shelf and slope, for a distance of about 80 miles from the coast. It presents an important perspective on structure and other aspects of regional geology.

Along with the cross section, the 5- by 3½-foot sheet includes gravity and magnetic profiles and a geologic strip map for the onshore portion as well as both onshore and offshore seismic reflection profiles. The accompanying 10-page text discusses stratigraphy and structure of the area the section line crosses.

The new DOGAMI publications are now available at the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 731-4066. Orders under $50 require prepayment except for credit-card orders. Purchase by mail and over the counter is also possible at the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496. □

MINERAL EXPLORATION ACTIVITY

MAJOR MINERAL EXPLORATION ACTIVITY

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Cracker Creek Mine Bourne Mining Corp.	T. 8 S. R. 37 E.	Gold	Expl
Baker 1991	Aurora Ridge Western Cons. Mines	T. 10 S. Rs. 35.5, 36	Precious metals	Expl
Baker 1991	Cave Creek Nerco Exploration	Tps. 11, 12 S. R. 42 E.	Gold	App
Baker 1991	Gold Hill Golconda Resources	T. 12 S. R. 43 E.	Gold	App
Baker 1991	Gold Powder Kennecott Expl. Co.	Tps. 9, 10 S. Rs. 41, 42 E.	Gold	Expl
Baker 1991	Gold Ridge Mine Golconda Resources	T. 12 S. R. 43 E.	Gold	Expl
Baker 1992	Pole Creek Placer Dome U.S.	T. 13 S. R. 36 E.	Gold, silver	Expl
Baker 1992	Bigelow prospect Yellow Eagle Mining	T. 7 S. R. 45 E.	Gold	Expl
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	Chromite, zircon	Expl com
Crook 1988	Bear Creek Independence Mining	Tps. 18, 19 S. R. 18 E.	Gold	Expl
Curry 1992	Mindoro Project Mindoro Corporation	T. 36 S. R. 12½ W.	Precious metals	Expl
Grant 1991	Buffalo Mine American Amex	T. 8 S. R. 35½ E.	Gold	App
Grant 1992*	Quartzburg Placer Dome U.S., Inc.	T. 12 S. R. 33 E.	Precious metals	Expl
Harney 1990	Pine Creek Battle Mtn. Exploratn.	T. 20 S. R. 34 E.	Gold	Expl
Harney 1991	Flagstaff Butte Noranda Exploration	Tps. 3, 9 S. R. 37 E.	Gold	App
Harney 1992	Celatom Mine Eagle-Picher Minerals	Tps. 19, 20 S. Rs. 35-37 E.	Diatoms	App
Jackson 1991	Al Sarena Project Fischer-Watt Gold Co.	T. 31 S. R. 2 E.	Gold	App
Josephine 1992	Eight Dollar Mountain Doug Smith	T. 38 S. R. 8 W.	Gold	Expl
Lake 1988	Quartz Mountain Wavecrest Resources.	T. 37 S. R. 16 E.	Gold	Expl
Lake 1990	Glass Butte Galactic Services	Tps. 23, 24 S. R. 23 E.	Gold	Expl
Lake 1991	8th Drilling Series Wavecrest Resources	T. 37 S. R. 17 E.	Gold	Expl
Linn 1991	Hogg Rock Oreg. St. Highw. Div.	T. 13 S. R. 7½ E.	Rock	App
Linn 1991	Quartzville Placer Dome U.S.	T. 11 S. R. 4 E.	Gold, silver	App
Malheur 1988	Grassy Mountain Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl, com
Malheur 1988	Harper Basin Project Amer. Copper and Nickel	T. 21 S. R. 42 E.	Gold	Expl
Malheur 1988	Jessie Page M.K. Gold Co.	T. 25 S. R. 43 E.	Gold	Expl
Malheur 1988	Kerby Malheur Mining	T. 15 S. R. 45 E.	Gold	Expl, com
Malheur 1989	Hope Butte Chevron Resources	T. 17 S. R. 43 E.	Gold	Expl, com
Malheur 1990	Ali/Alk Atlas Precious Metals	T. 17 S. R. 45 E.	Gold	Expl
Malheur 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E.	Gold	Expl
Malheur 1990	Freezeout Western Mining Corp.	T. 23 S. R. 42 E.	Gold	Expl
Malheur 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E.	Gold	Expl
Malheur 1990	Grassy Mtn. Regional Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Veg
Malheur 1990	Katey Claims Atlas Precious Metals, Inc.	Tps. 24, 25 S. Rs. 44, 46 E.	Gold	Expl
Malheur 1990	Mahogany Project Cyprus Minerals	T. 26 S. R. 46 E.	Gold	App
Malheur 1990	Racey Project Ican Minerals, Ltd.	T. 13 S. R. 41 E.	Gold	Expl
Malheur 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E.	Gold	Veg
Malheur 1990	Stockade Mountain BHP-Utah Internatl.	T. 26 S. Rs. 38, 39 E.	Gold	Expl
Malheur 1990	Stockade Project Phelps Dodge Mining	Tps. 25, 26 S. R. 38 E.	Gold	Expl
Malheur 1991	Bannock Atlas Precious Metals	T. 25 S. R. 45 E.	Gold	App
Malheur 1991	Big Red Ron Johnson	T. 20 S. R. 44 E.	Gold	Expl
Malheur 1991	Birch Creek Ronald Willden	T. 15 S. R. 44 E.	Gold	App
Malheur 1991	Harper Basin Atlas Precious Metals	T. 21 S. R. 42 E.	Gold	App
Malheur 1991	Quartz Mtn. Basin BHP-Utah Intl., Inc.	T. 24 S. R. 43 E.	Gold	App
Malheur 1991	Rhinehardt Site Atlas Precious Metals	Tps. 18, 19 S. R. 45 E.	Gold	Veg
Malheur 1991	Sagebrush Gulch Kennecott Exploration	Tps. 21, 22 S. R. 44 E.	Gold	App
Malheur 1991	White Mountain D.E. White Mtn. Mining	T. 18 S. R. 41 E.	Diatoms	App
Malheur 1992*	Shell Rock Butte Ronald Willden	T. 21 S. R. 44 E.	Gold, Silver	App
Marion 1990	Bornite Project Plexus Resources	T. 8 S. R. 3 E.	Copper	App com

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

Major mineral exploration activity

No major changes in mineral activity have taken place since the May issue of *Oregon Geology*.

MLR office adds FAX

The Mined Land Reclamation office can now be reached by FAX, no. (503) 967-2075. Address and phone number remain unchanged. (See listing on page 74 of this issue.) ☐

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OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

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GMS-37 Mineral resources, offshore Oregon. 1985	7.00	
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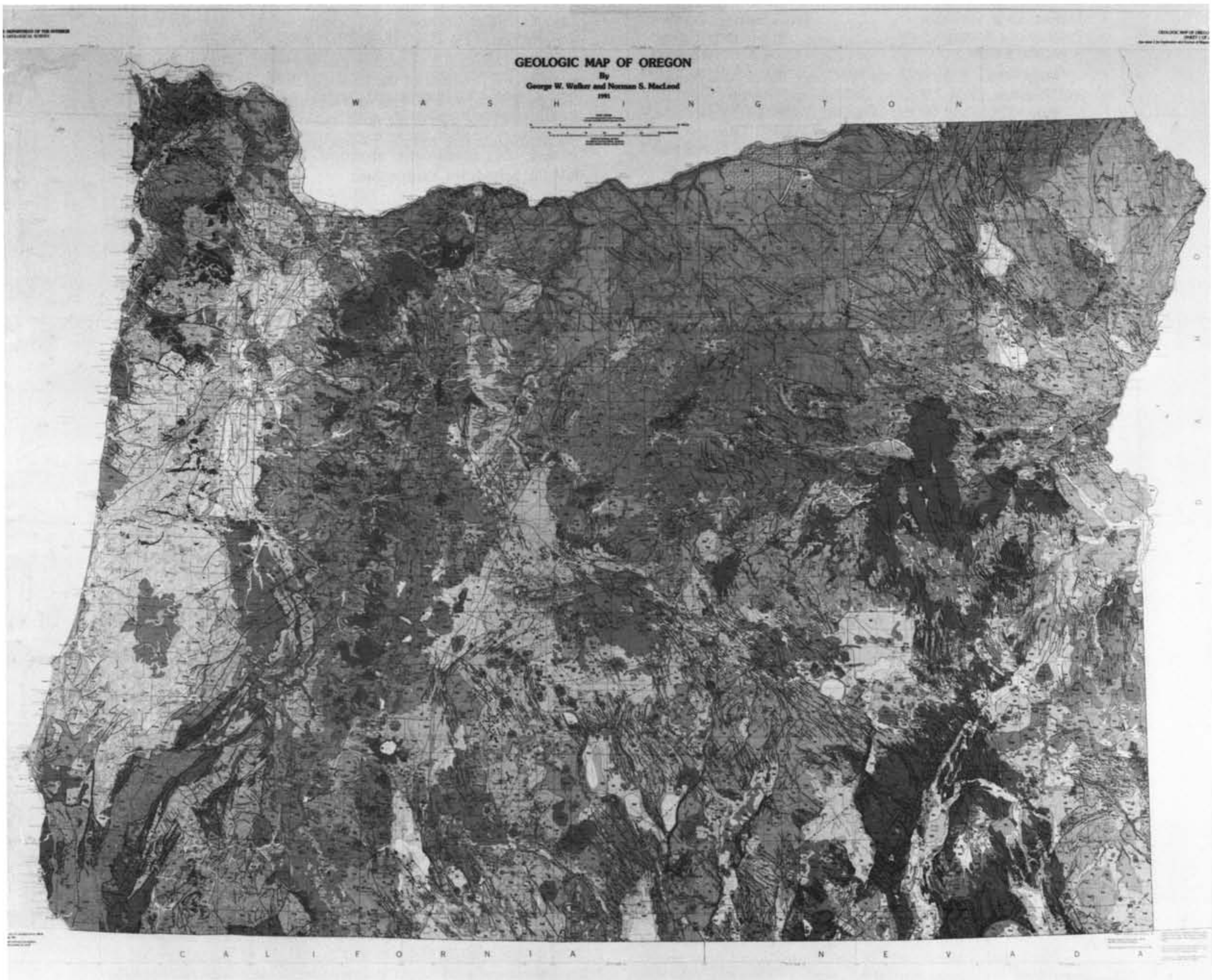
VOLUME 54, NUMBER 5 **SEPTEMBER 1992**



IN THIS ISSUE:

A History of Geologic Study in Oregon,
The Mount Angel Fault: Seismic-Reflection Data and the August 1990 Earthquakes
and
Geothermal Exploration in Oregon, 1991

OREGON GEOLOGY

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Information for contributors

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

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

Cover photo

Black-and white-reprint of the multicolored new geologic map of Oregon. A brief description of the new map is elsewhere on this page. The article beginning on page 105, on the history of geology in Oregon, includes a reproduction of the earliest geologic map of the entire state. See page 111 for an interesting illustration of the development of geologic knowledge about Oregon.

OIL AND GAS NEWS

Mist Gas Field activity

During May, June, and July, Nahama and Weagant Energy Company of Bakersfield, California, drilled three wells at the Mist Gas Field, Columbia County. Columbia County 23-31-65 is located in SW¼ sec. 31, T. 6 N., R. 5 W., and reached a total depth of 2,272 ft; Columbia County 32-33-75 is located in SE¼ sec. 33, T. 7 N., R. 5 W., and reached a total depth of 2,548 ft; Adams 31-34-75 is located in NE¼ sec. 34, T. 7 N., R. 5 W., and reached a total depth of 3,413 ft. All three wells are currently suspended. Taylor Drilling Company of Chehalis, Washington, was the drilling contractor for these wells.

During July and August, Nahama and Weagant Energy conducted an extended flow test of the CER 14-26-64 well, located in SW¼ sec. 26, T. 6 N., R. 4 W. This well was drilled during 1991 and is the easternmost gas well in the field. The flow test is used to determine the production rate and gas volume for the well.

NWPA schedules symposium

The Northwest Petroleum Association (NWPA) has scheduled the 1992 annual field symposium for October 11-13 in Lincoln City, Oregon. The theme for the symposium is "New Exploration Concepts and Opportunities for the Pacific Northwest." The symposium chairman is Bob Deacon, consulting geologist. Information can be obtained from NWPA, P.O. Box 6679, Portland, OR 97228-6679. □

New state geologic map available

The Oregon Department of Geology and Mineral Industries (DOGAMI), in cooperation with the U.S. Geological Survey (USGS), announces the release of the complete state geologic map for Oregon. This map is at a scale of approximately ⅛ inch to the mile (1:500,000) and is the product of 15 years of cooperative reconnaissance and compilation geologic mapping by DOGAMI, the USGS, and the Oregon Department of Higher Education.

The new multi-color map presents the entire state on a single map sheet approximately 42 by 54 inches in size. It supersedes and updates two earlier, now out-of-print USGS/DOGAMI reconnaissance geologic maps of the east and west halves of the state. A separate sheet contains explanations of rock units and bibliographic information.

Because of its scale and size, the map is necessarily general in its depiction of the state's geology. Therefore, it is primarily useful as a basis for more meaningful geologic mapping at larger scales and for planning priorities of more detailed geologic map projects by DOGAMI. Current efforts in the state are aiming at geologic mapping at the scale of 2½ inches to the mile (1:24,000). This scale allows a degree of detail that lends itself most readily to practical problem solving in such applications as environmental protection, public safety, economic development, and resource management.

The new map is now available at the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street # 5, Portland, OR 97232, phone (503) 731-4444. The price is $11.50 (rolled map only); if it is to be mailed, add $3.00 for the mailing tube. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 731-4066. Orders under $50 require prepayment except for credit-card orders. Purchase by mail and over the counter is also possible at the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496. □

Geothermal exploration in Oregon, 1991

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

INTRODUCTION

Geothermal exploration activity decreased in 1991 relative to 1990. No holes were drilled, and the amount of leased federal land continued to decline. The total amount of federal land leased for geothermal resources has declined steadily since the peak in 1983.

DRILLING ACTIVITY AND RESULTS

Figure 1 shows the number of geothermal wells drilled and geothermal drilling permits issued from 1970 to 1991. Figure 2 shows the same information for geothermal prospect wells (depths <610 m). Table 1 lists the Oregon Department of Geology and Mineral Industries (DOGAMI) permits and the geothermal drilling activity for 1991. Two new permits were issued, both for geothermal wells proposed by Anadarko Petroleum in the Borax Lake area of the Alvord Desert.

LEASING

The amount of leased federal land, while still decreasing, stopped the steep slide that occurred in previous years, changing by only a few percent from 1990 to 1991 (Table 2; Figure 3). Leasing revenue rose by about 35 percent, primarily as a result of a sale of competitive (KGRA) leases (Figure 4).

KNOWN GEOTHERMAL RESOURCE AREA (KGRA) SALES

Of the KGRA lands at Newberry that remained available after creation of the Newberry National Volcanic Monument, 6,822.19 acres were offered for lease on June 20, 1991. Bids totaling $71,940 were received for 3,513.21 acres of this land. Eagle Exploration and CE Exploration obtained lease positions.

REGULATORY ACTIONS

Drilling in the Alvord Desert by Anadarko Petroleum Corporation is still stalled pending review of appeals filed by various environmental organizations concerned about potential threats to the Borax Lake chub. No further exploration will occur until the Interior Board of Land Appeals makes a decision.

DIRECT-USE PROJECTS

The direct use of relatively low-temperature geothermal fluids continued in 1991 at about the same level as over the last several years. Most of the activity is centered in Klamath Falls and Vale, including the district heating system in Klamath Falls and the Oregon Trail Mushroom Company, the grain-drying facility of Ag-Dryers, and other direct users in Vale. Other users continue to operate in Ashland, La Grande, and Paisley. In La Grande, a geothermally heated industrial park will be developed on county land east of the Hot Lake resort. Planning and coordination of this park are being handled through Union County Economic Development.

USGS ACTIVITIES

U.S. Geological Survey (USGS) work related to geothermal-energy research in Oregon during 1991 was concentrated mainly at Newberry caldera, Mount Hood, and Crater Lake volcano, and in the Bend area. In addition, hydrothermal fluid flow has been analyzed on a regional scale in the central Oregon Cascade Range.

Dave Morgan and Marshall Gannett designed and initiated a monitoring program for the collecting baseline hydrologic data at Newberry caldera. These data, which are necessary prior to any future permitting of geothermal development adjacent to the newly formed Newberry National Volcanic Monument, will include water

Table 1. *Geothermal permits and drilling activity in Oregon, 1991*

Permit no.	Operator, well, API number	Location	Status, proposed total depth (m)
116	Calif. Energy Co. MZI-11A (deepening) 36-035-90014-80	SW¼ sec. 10 T. 31 S., R. 7½ E. Klamath County	Abandoned; confidential.
117	Calif. Energy Co. MZII-1 (deepening) 36-035-90015-80	SE¼ sec. 13 T. 32 S., R. 6 E. Klamath County	Abandoned; confidential.
118	GEO-Newberry N-1 36-017-90013	SW¼ sec. 25 T. 22 S., R. 12 E. Deschutes County	Unlawfully abandoned; 1,387.
125	GEO-Newberry N-2 36-017-90018	SW¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Unlawfully abandoned; 1,337.
126	GEO-Newberry N-3 36-017-90019	NE¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Unlawfully abandoned; 1,220.
131	GEO-Newberry N-4 36-017-90023	NE¼ sec. 35 T. 21 S., R. 13 E. Deschutes County	Unlawfully abandoned; 703.
132	GEO-Newberry N-5 36-017-90024	NE¼ sec. 8 T. 22 S., R. 12 E. Deschutes County	Unlawfully abandoned; 988.
139	Oxbow Power Corp. 77-24 36-031-90001	SE¼ sec. 24 T. 13 S., R. 7½ E. Jefferson County	Suspended; 928.
144	Anadarko Petroleum 52-22A 36-025-90004	NE¼ sec.22 T. 37 S., R. 33 E. Harney County	Canceled.
145	Anadarko Petroleum 66-22A 36-025-90005	SE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Canceled.
146	Calif. Energy Co. MZI-1 36-035-90020	NW¼ sec. 3 T. 30 S., R. 6 E. Klamath County	Canceled.
147	Calif. Energy Co. CE-BH-7 36-017-90032	NW¼ sec. 20 T. 17 S., R. 10 E. Deschutes County	Suspended; confidential.
148	Anadarko Petroleum 25-22A 36-025-90006	SW¼ sec. 22 T. 37 S., R. 33 E. Harney County	Canceled.
149	Calif. Energy Co. CE-BH-5 36-017-90033	NW¼ sec. 25 T. 16 S., R. 9 E. Deschutes County	Canceled.
150	Anadarko Petroleum 55-22A 36-025-90007	NW¼ sec. 22 T. 37 S., R. 33 E. Harney County	Permitted; 762.
151	Anadarko Petroleum 66-22A 36-025-90008	SE¼ sec. 22 T. 37 S., R. 33 E. Harney County	Permitted; 762.

analyses from the caldera lakes, Paulina Creek, wells in the caldera, and hot springs. Additional future monitoring may include more precisely measured evaporation and recharge rates, air-borne infrared surveys to monitor heat flux at thermal features, heat-flow measurements from the floors of East and Paulina Lakes by probes dropped into muddy bottom sediments, systematic sampling of Paulina Creek to determine extracaldera solute flux, and monitoring of outlying wells on the volcano's west side.

John R. Evans (USGS) and Jay J. Zucca (Lawrence-Livermore Laboratory) wrote a chapter, including results of active source high resolution seismic tomography from Newberry volcano, for a book on seismic tomography (Evans and Zucca, 1992). The authors infer that the young silicic magma chamber has largely solidified. They directly image a probable, large, two-phase geothermal reservoir (boiling water) beneath the southern and western ring fracture, and extending west of the caldera.

Craig Weaver and Dan Dzurisin are seeking to establish more complete seismic coverage and leveling data, both of which might be critical for recognizing pumpage-induced seismicity or ground subsidence.

Terry Keith and Keith Bargar completed two reports for U.S. Geological Survey Bulletins on (1) hydrothermal alteration of geothermal drill holes from the flanks of Newberry volcano and within the caldera, and (2) hydrothermal alteration of geothermal drill holes and rock outcrops near Mount Hood.

Bargar also examined hydrothermal alteration in selected samples from the SUNEDCO 58-28 drill hole near Breitenbush Hot Springs. Fluid-inclusion analyses from calcite and anhydrite cleavage chips at several depths within this drill hole allowed the determination of minimum homogenization temperatures. For nine samples from below 800-m depth, temperatures plotted fairly close to the temperature-depth curve reported by Blackwell and others (1986). Maximum homogenization temperatures for most samples are less than 150°C.

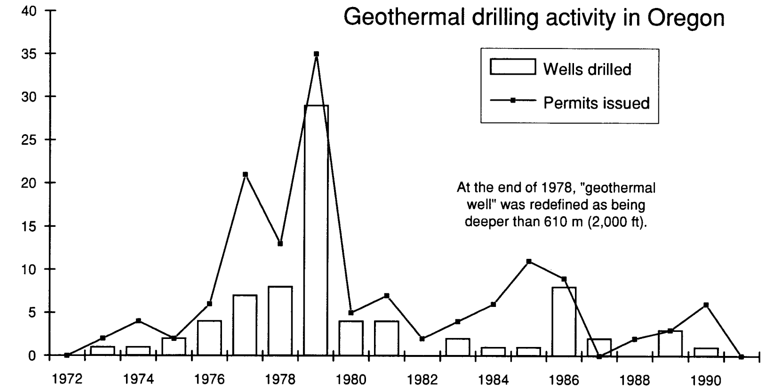

Figure 1. Geothermal well drilling activity in Oregon since 1972.

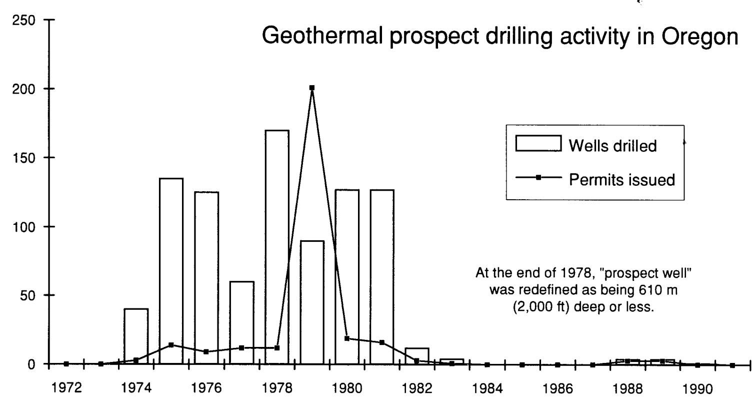

Figure 2. Geothermal prospect well drilling activity in Oregon since 1972.

Crater Lake studies by Charlie Bacon resulted in the completion of several manuscripts now being published in scientific journals: (1) partially melted granodiorite blocks ejected in the caldera-forming eruptions; (2) pre-eruptive volatile contents of Holocene silicic magmas; (3) petrology of pre-Mazama rhyodacite lavas; and (4) distribution of lithic clast types in deposits of the climactic eruption. A short field season was devoted to completing sampling of the southern caldera walls in order to finalize geologic panoramas.

A diverse study of Mount Hood and surrounding area continues, with emphasis mainly on hydrology and volcanic hazards. Willie Scott, Jim Vallance, and Tom Pierson concentrated on stratigraphic studies and mapping of late Pleistocene and Holocene pyroclastic-flow and debris-flow deposits on the south and west flanks of Mount Hood and in the Sandy River drainage. Cynthia Gardner began a paleomagnetic study of the three most recent eruptive periods. Bob Tilling and Joe Arth obtained strontium and neodymium isotope analyses from several samples—main-stage lavas as well as post-glacial eruptive products—previously analyzed for major and trace elements by Craig White (Boise State University). These reconnaissance data demonstrate a remarkable uniformity in isotopic composition, which needs to be confirmed by a broader sampling of the volcano's output through time and from rocks on all flanks. Dave Sherrod mapped pre-Mount Hood strata north of the volcano, where three previously unrecognized faults cut Pleistocene andesite and basalt on Blue Ridge. The faults strike north to north-northwest and have displacements of less than 60 m, but they probably have been inactive in Holocene time.

Sherrod's previous mapping of a part of the Cascade Range from south of the Three Sisters to Crater Lake was published as a full-color map (Sherrod, 1991). Potassium-argon ages obtained for this publication indicate that the age of Mount Thielsen is about 0.3 Ma. In view of the amount of erosion at Thielsen, it seems likely that Diamond Peak and Mount Bailey are younger than about 0.1 Ma.

Middle Pleistocene pyroclastic deposits in the Bend area received attention, because their relatively youthful age and silicic composition indicate magma-related geothermal systems that might still retain heat. A newly published map shows the distribution of part of these deposits (Mimura, 1992). Additional work to better secure the age of the Bend deposits was conducted by Cynthia Gardner and Andrei Sarna-Wojcicki, who, in conjunction with Brittain Hill (Oregon State University) and Rob Negrini (California State University, Bakersfield), determined the paleomagnetic signatures of the Bend deposits and presumably correlative distal ash beds. The paleomagnetic study (Gardner and others, 1992) supports earlier geochemical evidence correlating the Shevlin Park and Desert Spring Tuffs near Bend with Summer Lake (JJ) and Rye Patch Dam ash beds, respectively. Although the Shevlin Park Tuff and the Summer Lake ash bed have virtually identical paleomagnetic directions, which is strong evidence for their deposition during the same eruptive episode, present age interpretations differ by 200,000 years.

In an effort to better understand circulation of hydrothermal waters in the Cascade Range, Bob Mariner, Bill Evans, and Steve Ingebritsen have begun examining iodine-129 concentrations in some of the hot-spring waters. An Eocene age for the iodine is indicated by a sample collected from John Bigelow's thermal well at Belknap Hot Springs. When considered with the anomalously high N_2/Ar ratio of the dissolved gases and the ^{15}N-enriched nature of the gases, these data may indicate the presence of Eocene marine

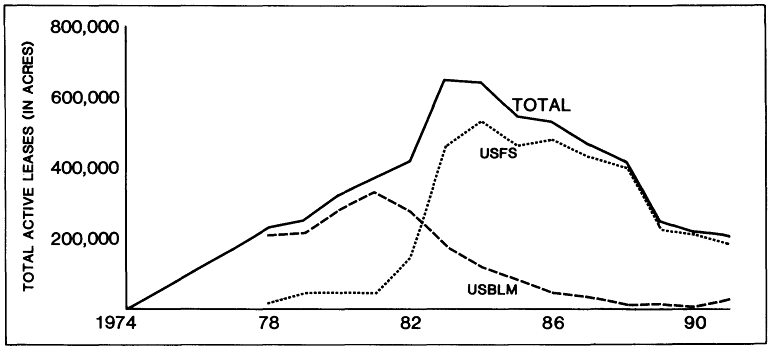

Figure 3. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December 1991.

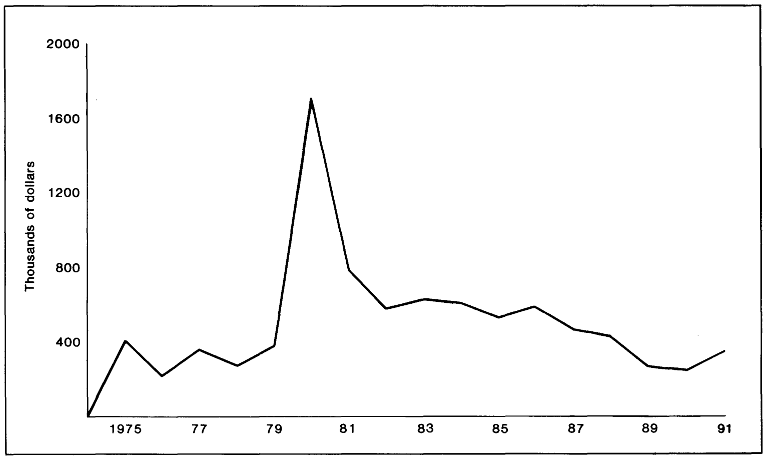

Figure 4. Federal income from geothermal leases in Oregon from the inception of leasing in 1974 through December 1991.

rocks beneath the High Cascades. The preliminary nature of these findings is stressed, however; another sample is being analyzed, and several more sites may need sampling before the age interpretation can withstand scrutiny.

Results of Ingebritsen's modeling of fluid flow from the High Cascades westward into the Western Cascades have been summarized (Ingebritsen and others, 1992), and a fuller data set and description of the hydrologic and geologic setting are available to support these interpretations (Ingebritsen and others, 1991). Four drill holes were completed in 1991 to test geothermal gradients. They range in depth from 90 to 150 m and were sited near the boundary between the Western Cascade and High Cascade physiographic subprovinces to better constrain the heat-flow map and perhaps resolve some of the controversy regarding location of heat sources. Publication of the heat-flow values is awaiting thermal conductivity measurements.

Table 2. *Geothermal leases in Oregon in 1991*

Types of leases	Numbers	Acres
Federal leases in effect:		
Noncompetitive, USFS	126	181,074.65
Noncompetitive, USBLM	2	942.79
KGRA, USFS	10	5,533.19
KGRA, USBLM	7	16,465.12
Total leases issued (since 1974):		
Noncompetitive, USFS	369	693,839.97
Noncompetitive, USBLM	266	406,157.79
KGRA, USFS	17	17,357.80
KGRA, USBLM	62	118,307.85
Total leases relinquished (since 1974):		
Noncompetitive, USFS	243	512,765.32
Noncompetitive, USBLM	264	405,215.00
KGRA, USFS	7	11,824.61
KGR, USBLM	55	101,842.73
Lease applications pending	97	—

DOGAMI APPLIED RESEARCH

Analysis of geophysical and geologic data from the Santiam Pass 77-24 drill hole, drilled for a scientific drilling program administered by DOGAMI and completed in 1990, was aimed at a better understanding of the geologic history and regional heat flow near the axis of active volcanism in the Cascades. A final temperature log in 1991, about one year after drilling, showed continued cooling of the hole by cold water entering at a depth of 150 m (Figure 7). Whereas large-volume, rapid flow of cold ground water occurs above 180 m, rock alteration greatly curtails this flow at greater depths (Hill and others, 1991). The low temperatures in the continuous temperature-depth curves from 180 m to 900 m are caused by flow of the cold shallow water that descends down the open borehole and exits at about 900 m (Hill and others, 1991). This effect is apparent when the bottom-hole temperatures taken during drilling are compared with the cooler temperatures measured after drilling (Figure 7). Heat flow measured below 718 m is 86-204 mW/m^2, bracketing the average of 105 mW/m^2 for the High Cascade Range (Hill and others, 1991). Heat flow and gradients inferred from the bottom-hole temperatures taken during drilling in the upper part of the hole are generally below average for the High Cascade Range.

This hole and nearby temperature gradient holes are not deep enough to determine with certainty the regional thermal structure or fluid flow conditions. However, it is clear that the anomalously low gradients in the upper part of the Santiam Pass hole are the result of infiltration of cold meteoric water. This masking effect of cold ground water at shallow depths in young volcanic terrains is well known and apparently extends to great depths at the crest of the High Cascades in central Oregon.

Those interested in conducting scientific studies of the drill hole or samples are encouraged to contact this author for further information. Plugging of the hole has been delayed by a year so that the hole will be accessible for experiments in the early summer of 1992, but it will be plugged and abandoned thereafter. Drill core and cuttings from the hole are stored at Oregon State University (OSU) in Corvallis. Contact Brittain E. Hill, Department of Geosciences, Oregon State University, Corvallis, OR 97331-5506 (phone 503-737-1201) for access to cores and cuttings.

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

In late 1991, DOGAMI began working collaboratively with the Bonneville Power Administration (BPA) on a project aimed at reducing exploration costs in young volcanic terrain and updating geothermal resource estimates in the Oregon Cascades. DOGAMI will study existing temperature-depth and geophysical

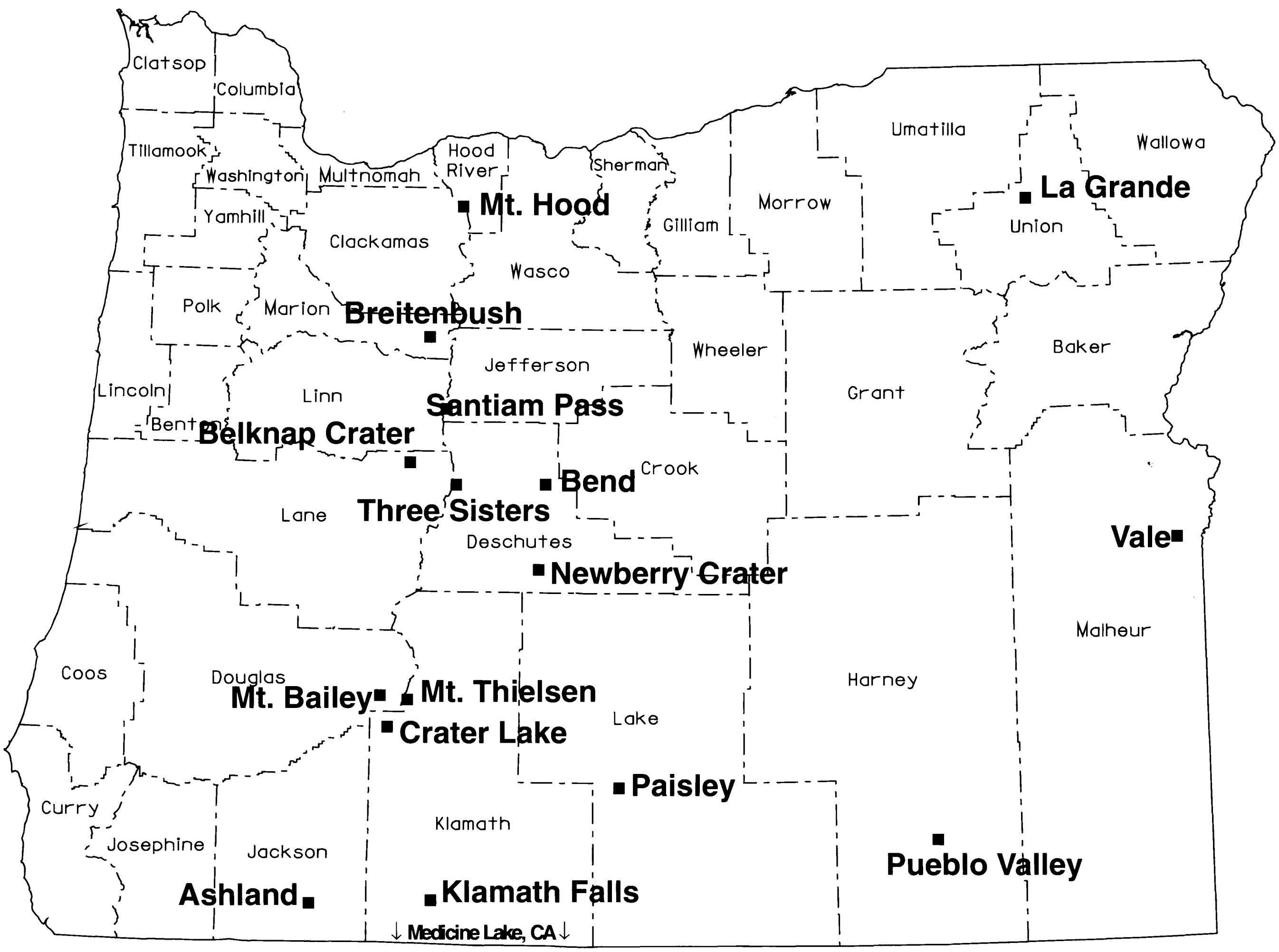

Figure 5. Major areas of geothermal activity in Oregon during 1991 that are discussed in the text.

data from young volcanic areas of Oregon to determine whether a means can be developed to predict the thickness of the cold, isothermal part of the volcanic pile known as the "rain curtain" or "cold water blanket." Exploration costs could be cut significantly if it were known in advance how deep to drill to penetrate depths below this zone. At present, most companies simply drill to depths of 1.2 km to obtain reliable temperature gradients in this terrain, whereas in many cases shallower holes could be drilled for the same information.

The DOGAMI-BPA project will also update estimates of the geothermal power potential of the Oregon Cascades and Newberry volcano. Results of the study will be available in 1993.

GEO-HEAT CENTER, OIT

The Geo-Heat Center, Oregon Institute of Technology (OIT), Klamath Falls, provides geothermal developers with (1) preliminary engineering, technical and development assistance; (2) research to aid in resource and technical development problems; and (3) information and educational materials to stimulate development. This program is supported by the Geothermal Division of the U.S. Department of Energy.

During 1991, technical assistance was provided to 309 developers throughout the U.S., including 77 in Oregon. Typical users of the program were individuals, businesses, public institutions, and municipal governments. They received assistance in the forms of information and data on geothermal resource sites, preliminary engineering, review of consultant designs, equipment selection, and troubleshooting of problems after projects were completed.

In Oregon, the most significant development has been the drilling of 12 geothermal injection wells in the Klamath Falls area, many of which received technical assistance.

Geothermal direct-use research was applied in three areas to assist users with reducing costs of developing, designing and operating low-temperature projects. In 1991, these included corrosion evaluation of brazed plate heat exchangers, environmental impact of using vertical pump turbine oil, injection well design, and data acquisition techniques for well testing and long-term monitoring.

The technology transfer program is designed to provide the general public, potential users, consulting engineers and government agencies with information on geothermal resources and their uses, including geothermal heat pumps. Technical information on project designs, technology advances, new products and material selections were provided to potential users and designers of geothermal systems. This effort included publication of the *Geothermal Direct Use Engineering and Design Guidebook*, 2nd edition, and of the quarterly *Bulletin* and topical papers; arrangement of presentations and tours of geothermal facilities; and maintaining a geothermal library. For publication listings and information on the technical assistance program, contact the Geo-Heat Center, Oregon Institute of Technology, 3201 Campus Drive, Klamath Falls, OR 97601, phone (503) 885-1750.

ACTIVITIES OF OREGON DEPARTMENT OF ENERGY

In 1991, the Oregon Department of Energy (ODOE) performed geothermal research for outside organizations and provided assistance to the public. Research included work for Bonneville Power Administration (BPA) and joint work with the Washington State Energy Office (WSEO). Technical assistance includes giving talks to the public and professionals, answering siting questions and reviewing tax credit applications.

Geothermal research completed in 1991 for BPA included economic impact studies and creating a power plan database. For the first task, ODOE estimated local economic impacts of a 100-megawatt (MW) geothermal power plant project. These impact estimates were done for hypothetical projects in Deschutes and Harney Counties, Oregon. Further research for BPA includes assembling a database of existing geothermal power plants in the United States. Data on more than 60 plants is collected on a FoxBASE+/Mac™ data base program. This task is nearing completion in early 1992.

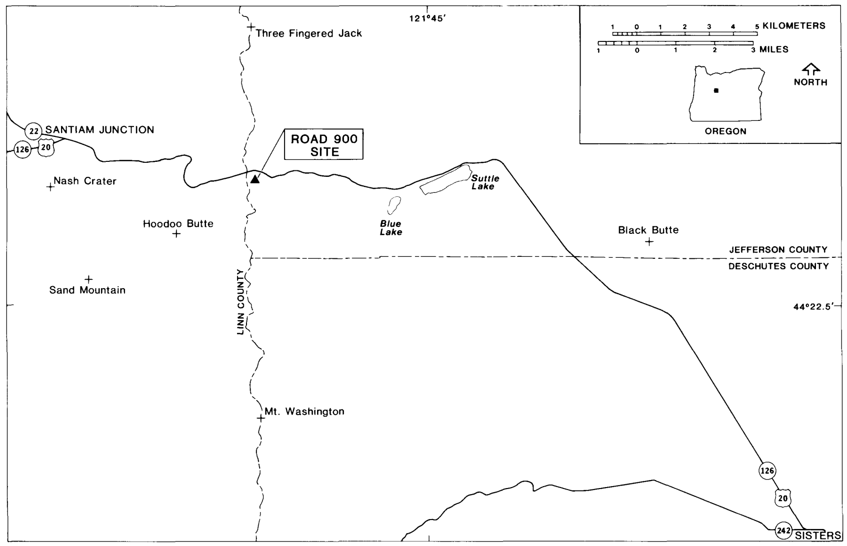

Figure 6. Location of drill site for drill hole 77-24, Santiam Pass scientific drilling project. Hole is located about 100 m south of Highway 22 on Forest Road 900.

Geothermal research in 1991 with WSEO included digital mapping of the Newberry volcano and Pueblo Valley areas, covering several 7½-minute quadrangles and including layers for cultural resources, roads, topography, and well location. This work is part of a regional effort to create renewable energy site maps for the northwestern states. One site was digitized by ODOE in 1991. The Pueblo Valley site will be digitized in 1992. The goal is to include all significant renewable energy sites in all northwestern states.

ODOE's geothermal specialist reported results of the Harney County study and published a paper for the annual Geothermal Resources Council meeting.

ODOE's geothermal specialist met several times in 1991 with state and regional environmental organizations to discuss the acceptability of future power plants. Much progress is being made in explaining alternative power supply impacts to these groups.

ODOE continues to certify geothermal tax credits for both homes and businesses in the state. ODOE's tax credit staff assumed responsibility for geothermal tax credit reviews from the geothermal program manager in 1991. Staff reviewed 130 residential tax credit applications in 1991. In addition, 123 residential systems received final certification, the prerequisite for tax credit applications. The total number of submitted geothermal business energy tax credit applications were reviewed in 1991; all were ground source heat pumps. This brings the total number of geothermal business energy tax credits issued from 1980 through 1991 to 48.

ODOE responds to public inquiries on geothermal energy development. ODOE answered 114 such inquiries in 1991. These inquiries have averaged 127 requests annually since 1984.

BONNEVILLE POWER ADMINISTRATION

The Bonneville Power Administration (BPA) issued a solicitation for three geothermal pilot projects located in the Pacific Northwest. The purpose of the solicitation is to initiate development in three areas with potential for large-scale power production. Ability to solve technical and siting problems will be tested, thus allowing regional utilities to gauge future availability of this resource.

From the seven proposals received, three 30-MW projects were selected in December for further consideration. The proposed projects are located at Newberry volcano and Vale in Oregon and at Glass Mountain (Medicine Lake area) near the Oregon border in northern California. Contract discussions will be held in early 1992. Commercial operation for all three projects is expected in 1995 or 1996.

BPA funded work by the Water Resources Division of the USGS to design a hydrologic monitoring network at Newberry volcano. The purpose of the network is to establish a baseline of predevelopment data which can be used to assess impacts of future geothermal power projects. The USDA Forest Service will cofund implementation of this design in 1992. Baseline monitoring programs will also be designed for air quality and biology in 1992. The USGS also designed a hydrologic monitoring network for the Borax Lake area.

A two-year study by Portland State University to characterize the Alvord Valley geothermal system began in 1991. The study is being done by Anna St. John and Michael Cummings.

As previously mentioned, BPA is also funding DOGAMI to perform a study to better characterize the "cold water blanket" in the

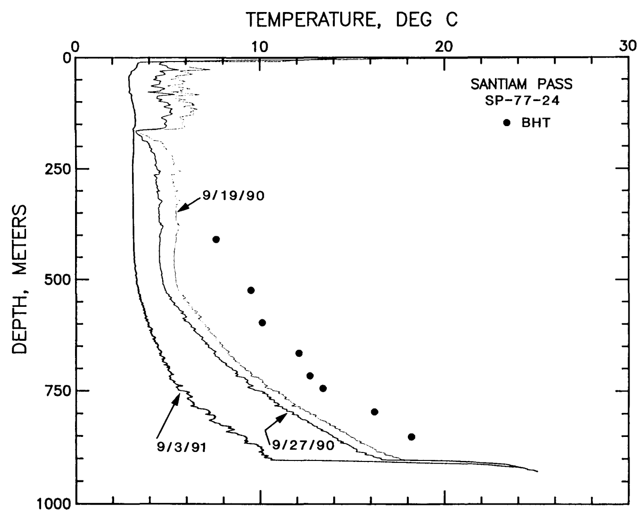

Figure 7. Temperature-depth data from Santiam Pass drill hole 77-24. Note the rapid increase of temperature near the bottom and continued cooling of the lower part of the well by cold ground water entering at about 150 m, flowing down the open hole, and exiting at about 900 m. Gradients estimated from bottom-hole temperatures (BHT) are on the order of 15°C/km between 160 and 750 m, about 50–60°C/km between 750 and 850 m, and about 100-120°C/km at the bottom of the hole (Hill and others, 1991).

Cascades and update the Casacade geothermal resource assessment. Results of these studies are expected in mid-1993.

ODOE completed studies of the economic impacts of a 100-MW geothermal project in two Oregon counties. The two resulting reports, "Economic Impacts of Geothermal Development in Deschutes County, Oregon," and "Economic Impacts of Geothermal Development in Harney County, Oregon," are available from ODOE or BPA.

"Geothermal: A Regulatory Guide to Leasing, Permitting, and Licensing in Idaho, Montana, Oregon, and Washington" was prepared by the Washington State Energy Office, in cooperation with the ODOE and the other state offices. This publication is also available from ODOE and BPA.

ACTIVITIES OF OREGON WATER RESOURCES DEPARTMENT

The low-temperature geothermal resources program of the Oregon Water Resources Department (WRD) has been assigned to Sam Allison. Sam is an Oregon Certified Engineering Geologist and a 20-year employee of WRD.

WRD's Division 230 administrative rules deal with low-temperature geothermal resources. This division contains standards and procedures for low-temperature geothermal production and injection wells and effluent disposal systems. It also contains definitions for "substantial thermal alteration" and "substantial thermal interference."

Users in the Klamath Falls area have not completely switched to injection of spent geothermal effluent. OIT is constructing a second injection well for its system. The Oregon Department of Transportation is reconstructing a geothermal well used for de-icing Esplanade Street. Several smaller users have experienced difficulties in constructing and gaining access to injection wells.

Last summer, the District Utility Services Company tested production and injection wells for a heat pump system at the Inn of the Seventh Mountain near Bend. The company is also in the process of planning a system in the Lloyd Center area of Portland.

RESEARCH BY OREGON STATE UNIVERSITY

Brittain E. Hill has completed his studies at Oregon State University (OSU) with a dissertation on silicic rocks in the Three Sisters/ Broken Top area (Hill, 1991). He works part-time for DOGAMI as the field supervisor for scientific work on the scientific drill hole at Santiam Pass. He plans to summarize the data collected there in a series of publications.

Jack Dymond and Robert Collier of the OSU Oceanography Department finished their investigation at Crater Lake National Park. Their objective was to determine whether or not geothermal inputs exist on the floor of the lake. Data collected in 1989 from a surface ship and submarine were analyzed and summarized in a final report to the National Park Service. Further information is now available from the National Park Service, Pacific Northwest Region, 83 South King Street, Suite 212, Seattle, Washington 98104.

MOUNT MAZAMA AREA (CRATER LAKE AREA)

The reader is referred to Black and Priest (1988) and Priest (1990) for a detailed history of geothermal development issues at Mount Mazama. The California Energy Company leases and the leasing unit on the flanks of Mount Mazama are officially under suspension by BLM, so no new exploration can occur on the leases and no leasing fees are being collected until the suspension is lifted. It seems unlikely that any new exploration activity will occur in the near future.

ACKNOWLEDGMENTS

Numerous individuals in government and industry cooperated in preparing this summary. Jacki Clark of the U.S. Bureau of Land Management provided the federal leasing data. Dan Wermiel of DOGAMI furnished the data on drilling permits. George Darr of BPA, Alex Sifford of ODOE, and Sam Allison of WRD provided information on their agencies' activities for the year. Paul Lienau of OIT provided information on OIT activities and the status of direct-use projects around the state. David Sherrod of the USGS supplied an account of USGS activities in Oregon. Jack Dymond of Oregon State University provided information on his study of Crater Lake.

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AIPG announces annual meeting

The American Institute of Professional Geologists (AIPG) will hold its 1992 Annual Meeting September 27-30 at South Lake Tahoe, Nevada.

Theme of the meeting will be "Geological Reason, a Basis for Decisions Affecting Society." Five technical sessions will each consist of 20-minute presentations by three invited speakers and a panel discussion with written questions from the audience. Poster sessions with both volunteered and invited contributions may follow.

Three field trips before and two after the meeting will fit with the theme (technical) sessions. Workshops are planned but still tentative. Keynote speaker will be T.S. Ary, Director of the U.S. Bureau of Mines.

For information on any matter relating to the meeting, contact Jonathan G. Price, Nevada Bureau of Mines and Geology, Mail Stop 178, University of Nevada, Reno, NV 89557-0088; phone (702) 784-6691, FAX (702) 784-1709. *—AIPG news release*

A history of geologic study in Oregon

by Elizabeth L. Orr, Librarian, and William N. Orr, Department of Geological Sciences, University of Oregon, Eugene, Oregon 97403

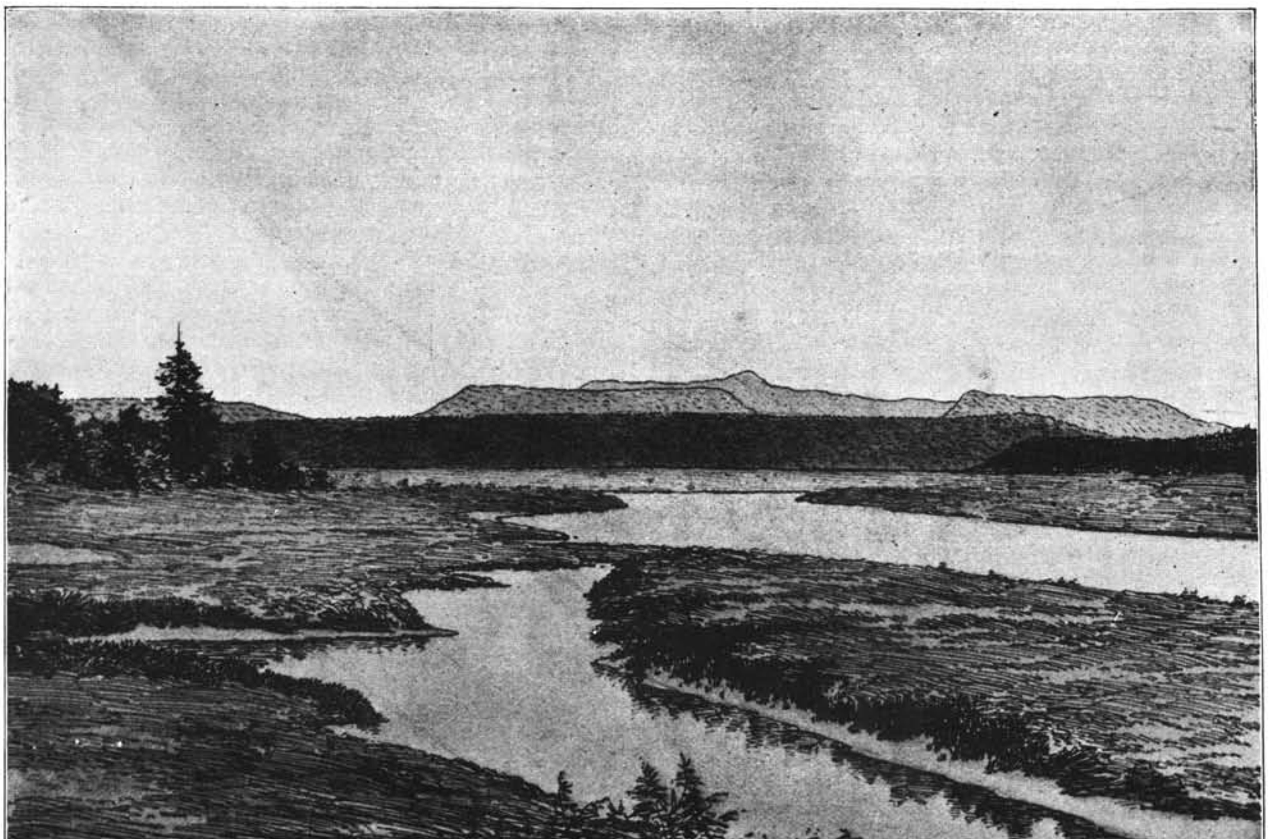
The following article is a somewhat simplified version of a chapter from the new book, Geology of Oregon, *by Elizabeth Orr, William Orr, and E.M. Baldwin, that is scheduled to be published by Kendall-Hunt later this year. —eds.*

The currency of science is the published literature. In this regard, the record of publications reflects the history of the development of geological sciences in Oregon.

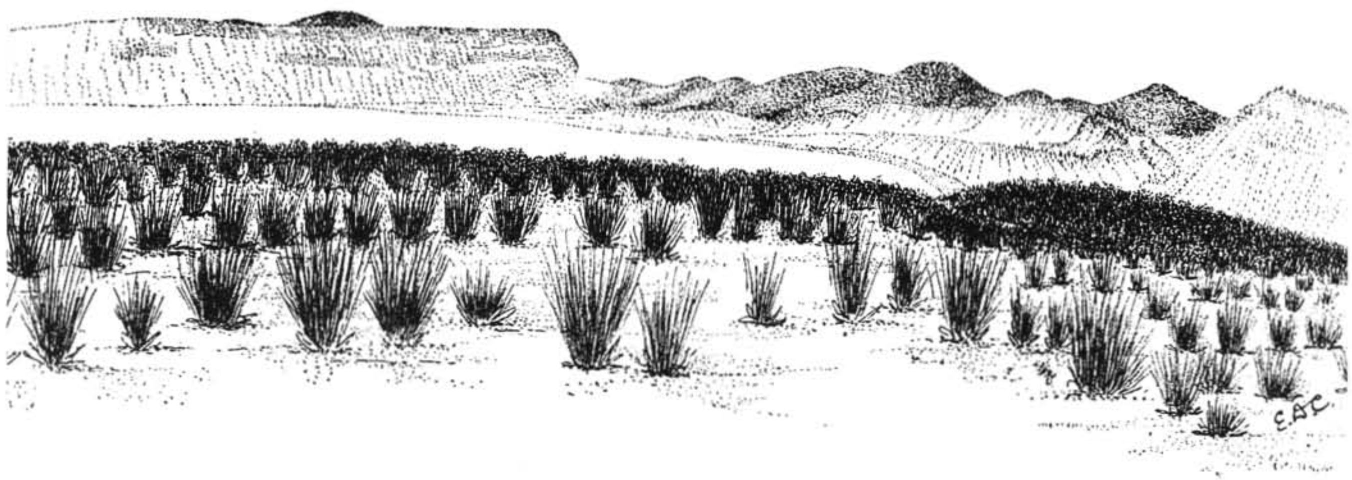
EXPLORING EXPEDITIONS

The study of geology in the Pacific Northwest began obliquely with the Lewis and Clark expedition, commissioned by President Thomas Jefferson in 1803 to explore the West to the Pacific Ocean. President Jefferson, in a lengthy letter of instructions, exhorted the party to look for the "remains and accounts of any [animals] which may be deemed rare or extinct. The mineral productions of every kind . . . [and] volcanic appearances." Jefferson was convinced that animals did not become extinct; and since he had seen bones of the giant sloth, *Megalonyx*, in Virginia, he felt that these huge beasts had migrated westward instead of disappearing from the earth. However, no one with training in geology accompanied the expedition. Thus, the resulting *History of Expedition under the Command of Lewis and Clark to the Sources of the Missouri, Thence Across the Rocky Mountains and Down the Columbia*, published in 1814, is of minimal geologic relevance.

Thirty years went by, including nearly ten years of debate in Congress, before a bill was passed on May 14, 1836, to outfit an exploring expedition to the southern polar regions as well as along the Pacific islands and the northwest coast of this continent. One purpose of this exploring expedition was to test the theory presented in Paris in 1721 and debated in America years later that holes in the polar regions led to the hollow interior of the earth. Theories such as this, combined with the desire for political and military expansion, economic gain, and scientific curiosity about western North America, led Congress to allocate funds for an expedition of six ships commanded by Charles Wilkes. The *Vincennes*, *Peacock*, *Relief*, *Porpoise*, *Sea Gull*, and *Flying Fish*



View looking toward Saddle Mountain from Youngs River below Olney, Clatsop County. Illustration from "A geological reconnaissance in northwestern Oregon," by J.S. Diller, U.S. Geological Survey 17th Annual Report, 1896.



Silver Lake, Lake County, looking southeast. Illustration from E.D. Cope, "The Silver Lake of Oregon and its region," American Naturalist, *v. 23, 1889.*

left Norfolk, Virginia, on August 17, 1838, with a team of scientists that included geologist James Dwight Dana. Dana, then 25 years of age, had taught at Yale University.

Rounding Cape Horn, the ships criss-crossed the Pacific, landing near Puget Sound on May 2, 1841. Arriving later than the others, the *Peacock*, with Dana aboard, was destroyed on a bar at the entrance to the Columbia River, but everyone survived the mishap. The Wilkes party explored between Puget Sound and Fort Vancouver before crossing the Washington Cascades and conducting surveys of the Columbia River Gorge. In August 1841, Commander Wilkes directed a party of men led by Lieutenant George Emmons to journey overland across the Klamaths to San Francisco, where they would meet with the *Vincennes* on September 30. The entire expedition returned to New York in June 1842.

Dana accompanied the San Francisco group, and his report provided a concise, geologic account of the region through which he traveled. Leaving the "Willammet" district, the party traversed the Umpqua Valley and climbed what Dana called the "Umpqua Mountains" and "a most disorderly collection of high, precipitous ridges and deep secluded valleys enveloped in forests." He was obviously referring to the Klamaths and Siskiyous in the area where the group was soon to encounter the Shasta River.

The magnificent volume 10 of the *United States Exploring Expedition during the Years 1838, 1839, 1840, 1841, 1842, under the Command of Charles Wilkes* contains Dana's "Geological Observations on Oregon and Northern California." The 145 pages contain the first formal geologic observations in this area. Unfortunately, Congress was in a parsimonious mood when it came to funding publication of the 18 volumes and 11 atlases of the expedition's final report, which took 30 years to complete, and allowed only 100 copies to be printed. For each state of the nation there was to be one copy, and the remaining copies were to go to foreign governments. Three private copies were given out, one of them to Dana, who also received $16,000 in pay for writing volumes 7, 10, 13, and 14. At the outset, 30 copies of volume 10 were destroyed by fire and never replaced. An angry Dana had 100 copies printed with his own funds and distributed them to private libraries. One of these "unofficial" copies exists in Oregon, at the University of Oregon Library in Eugene, although the accompanying atlas of illustrations is missing.

Dana observed and wrote extensively on the geologic features of Oregon, commenting on the mountain ranges bordering the oceans and the evidence of volcanic activity and describing the "abundance of basaltic rocks over its [Oregon's] surface," the granites of the Klamath area, and other rocks. The coastal rock units he listed were assigned to the Tertiary; the molluscs he collected from the Astoria Formation were subsequently identified by Timothy Conrad, renowned invertebrate paleontologist with the Philadelphia Academy of Sciences. Descriptions of fossil cetacean bones, fish, crustaceans, foraminifers, echinoids, and plants were incorporated in the report.

With his concluding remarks, Dana assessed Oregon's potential as a goal for settlers: "Although Oregon may rank as the best portion of western America, still it appears that the land available for the support of man is small . . . only the coast section within one hundred miles of the sea . . . is [at] all fitted for agriculture. And in this coast section there is a large part which is mountainous or buried beneath heavy forests. The forests may be felled more easily than the mountains, and notwithstanding their size, they will not long bid defiance to the hardy axeman of America. The middle section is in some parts a good grazing tract; the interior is good for little or nothing."

WESTERN JOURNEYS

Charles Fremont, although not a trained geologist, cannot be ignored in the history of the early geologic examination of the West. Certainly a person of curious and quixotic nature, Fremont could be called a "scientific explorer." He married Jessie Benton, daughter of the influential Senator Thomas Hart Benton from Missouri. After that, Fremont had no difficulty obtaining appointments and funding from Congress for his trips across the continent, including one in 1843 to survey the Oregon Territory. The purpose of this, his second of three western journeys, was political as well as scientific. The expedition was charged with reporting on the topography and collecting geologic and botanical specimens in order to gain any knowledge of the interior that might prove useful in substantiating the claim of the United States Government to the "valley of the Columbia."

The Fremont party of 39 men, which included the German map maker Charles Preuss, departed in the spring of 1843. Once the group had crossed the Rockies, it journeyed down the south bank of the Columbia to The Dalles. After a brief side trip to Fort Vancouver for supplies, the party explored the region east of the Cascades to Klamath Lake and south into California. Fremont's journal contains some notes of geologic interest; his main contribution, however, was a collection of some fossil plant specimens from the Cascades. These he sent to James Hall, New York State paleontologist, along with a map of Oregon and California.

The same year in which Congress restricted Dana's volume 10 to 100 copies, 1848, it generously funded the publication of 20,000 copies of Fremont's "Geographical Memoir upon Upper California" and Preuss' "Map of Oregon and Upper California." Most of the map was, in actuality, a synthesis of data on Oregon and California from previous trips and other sources. An earlier "Map of the Exploring Expedition to the Rocky Mountains in the Year 1842 and to Oregon and California in the Years 1843-4," published by Preuss in 1845, was well drawn and accurate, but the Willamette Valley and the Coast Range were left blank. These maps, as well as others of this period, were topographic only and lacked geology.

PACIFIC RAILROAD SURVEYS, 1853-1855

In 1853, an act of Congress was once again instrumental in furthering geologic knowledge of the Pacific Northwest. The act was designated to employ "such portion of the Corps of Topographical Engineers . . . to make such explorations and surveys . . . to ascertain the most practical and economical route for a railroad from the Mississippi River to the Pacific Ocean." Congress budgeted the sum of $150,000 for this project and sent out "a mineralogist and geologist, physician, [and] naturalist" under the leadership of the Army Corps of Topographical Engineers. These explorations, known as the Pacific Railroad Surveys, were conducted from 1853 to 1855, and the geologists employed to survey Oregon and northern California were John Evans and John S. Newberry.

The first Pacific Railroad Survey funded by the U.S. Government set out from St. Paul in 1853. John Evans was hired as the geologist of the expedition that was overseen by Isaac Ingalls Stevens, newly appointed Governor of the Washington Territory. Evans, whose training was in medicine, was charged with the geological reconnaissance of Oregon. Once in Oregon Territory, Evans began his work on the Columbia River, exploring much of Washington but eventually finding himself 150 miles south, on the Umpqua River. He then traversed to Empire, near Coos Bay, before returning north by way of the Willamette Valley and Vancouver. Unfortunately, the "Geological Survey of Oregon and Washington Territories" by Evans was never received by Stevens and was thought to have been lost. A partial log of Evans' trip was found 50 years later and deposited at the Smithsonian. The log was never officially published, although typewritten copies entitled "Route from Fort Vancouver, 1854-56" are available. With many gaps, however, and with references in the notes only to the lithology, the report is of limited geologic value.

Newberry, a professor of geology and chemistry of the School of Mines at Columbia College, New York, was titled the geologist and botanist of the survey that left San Francisco in 1855. This party was under the leadership of Lieutenant R.S. Williamson and Lieutenant Henry L. Abbot of the Topographical Engineers.

Once over the Sierra and the Klamath Mountains, the men spent a month crossing and recrossing the Cascades near the Three Sisters. Newberry was able to study the geology of the Cascade and John Day regions in great detail. The variety and color of the John Day beds impressed Newberry: "Some are pure white, others pink, orange, blue, brown, or green. The sections made by their exposure have a picturesque and peculiar appearance." Following the "Mptoly-as" (Metolius) and Deschutes Rivers, Newberry reported on the stratigraphy and structure of the canyons. The warm springs of the Deschutes were examined and analyzed separately by E.N. Horsford, who accompanied the party.

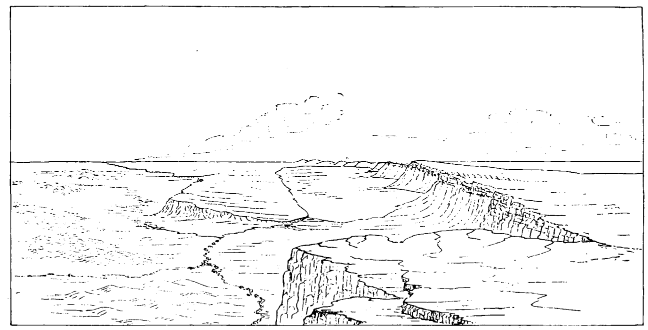
Newberry was the first to differentiate between the coastal chain in California and the Oregon Cascades. He correctly identified glacial features in the Cascades and erosional evidence in the Columbia River canyon. His most significant economic contribution was an account of the coal mining possibilities of "Coose Bay," Vancouver Island, and Cape Flattery.

Volume 6 of the Pacific Railroad Survey report was submitted to the War Department in 1855 and included the "Reports on the Geology, Botany, and Zoology of Northern California and Oregon," in which John Newberry's "Geological Report on Routes in California and Oregon" with its beautifully tinted plates appeared.

U.S. GEOLOGICAL SURVEY

With the end of the Civil War in 1865, the Government began funding excursions to the West in order to carry out observations in the natural sciences. Many publications resulted from four great western surveys conducted between 1867 and 1879 under Clarence King, Ferdinand V. Hayden, John Wesley Powell, and George M. Wheeler. Subsequently, the tasks and many of the scientific workers of those surveys were incorporated in the newly created U.S. Geological Survey (USGS) within the Department of the Interior.

Representative of the earliest published studies dealing with Oregon are Leo Lesquereux' "Description of Miocene Species of California and Oregon" in an 1883 monograph from the Hayden survey; Israel C. Russell's "A Geological Reconnaissance in Southern Oregon" of 1884, from the Wheeler survey; and the 1899 report on "The Coos Bay Coal Field, Oregon" by J.S. Diller, who between 1898 and 1903 also produced the first three Oregon folios for the USGS *Geologic Atlas of the United States.*



Sketch of Lake Abert, Lake County. Illustration from "A Geological Reconnaissance in Southern Oregon," by I.C. Russell, published in U.S. Geological Survey Fourth Annual Report, *1884.*

TURN OF THE CENTURY

About 1865, Thomas Condon had begun an informal study of Oregon geology and paleontology while he was stationed as a missionary at The Dalles. Condon made frequent trips to the John Day fossil beds, collecting mammal bones and leaves. His interest in geologic studies eventually forced him to choose between the ministry and a career in geology, a decision that came when he accepted an academic appointment at Forest Grove College in 1873.

The increasing attention given to Oregon geology precipitated the creation of the office of State Geologist in the fall of 1872. The appointment fell to Thomas Condon, and it was his duty "to make geological examination of different parts of the State from time to time," a job that was to pay $1,000 in gold annually. Several years after his appointment, the University of Oregon opened at Eugene, and Condon accepted a position there as a professor of geology in 1876.

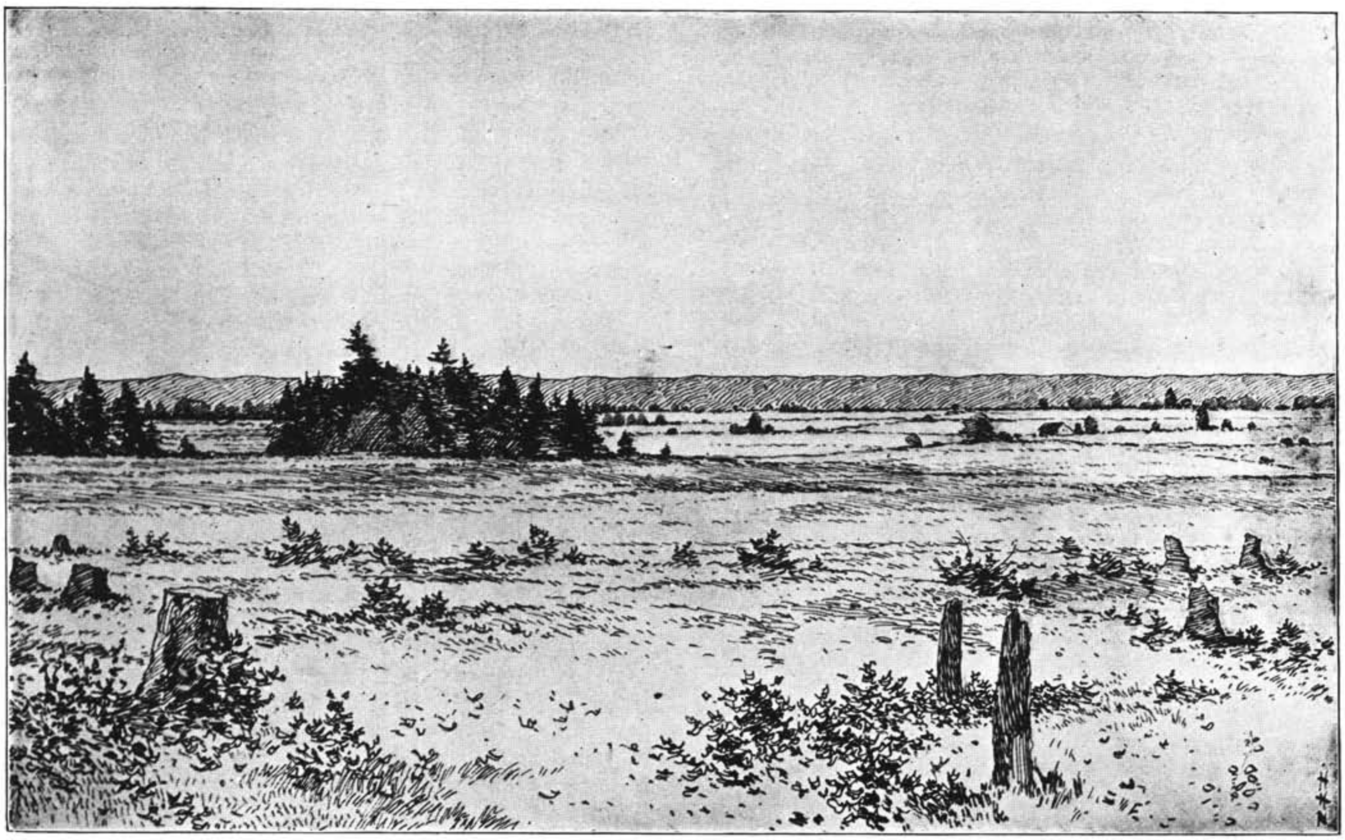
Condon, in his capacity as geology professor and State Geologist, living and working for years in Oregon, was in the position to develop a comprehensive theory on the geologic origin of the state. Condon's ideas were published in 1902 as *The Two Islands and What Came of Them.* This book appeared about 100 years after Lewis and Clark had reached the Northwest and 53 years after Dana's "Geological Observations." The significance of the book is that it attempts to summarize knowledge and scientific expertise on Oregon geology in order to draw conclusions about Oregon's geologic past, a task much more difficult than Dana's because of the increased information available around the turn of the century. In his introduction, Condon states, "But this large body of information is so scattered that few have the time to collect enough of it to form a continuous unity of its history." One of Condon's greatest contributions to expanding the knowledge of Oregon's geology was an outgrowth of his own intense interest in science. Condon carried on a voluminous correspondence with several prominent eastern scientists such as John Newberry, who had seen Condon's Miocene fossil leaves and requested more material. Condon had sent specimens to, and corresponded with, Spencer Baird of the Smithsonian Institution, Edward Cope of the Academy of Natural Sciences, Joseph Leidy of Philadelphia, O.C. Marsh of Yale University, and John C. Merriam of the University of California. Thus, the scientific community was not only aware of Oregon's geologic resources, but many took the time to come to Oregon to see the geology firsthand. Articles on Oregon paleontology and geology proliferated around the turn of the century as a consequence of these activities.

Condon was not alone in pushing forward the boundaries of geologic knowledge in Oregon. Among those who worked in the northwest, mineralogist and stratigrapher Joseph S. Diller stands out as having contributed significantly to the geologic record. Diller produced 56 papers and maps on Oregon while employed by the U.S. Geological Survey. Among his important early works are "The Bohemia Mining Region of Western Oregon" (1900), the first extensive study of the newly created Crater Lake National Park (1902), and a number of outstanding geologic quadrangle maps of southwestern Oregon for the *Geologic Atlas of the United States*. The "Port Orford Folio" was issued in 1903 and the "Riddle Folio" in 1924.

Diller's efforts produced the first detailed geologic maps of portions of Oregon. Up to this point, a number of maps on the geology of the United States had been composed, such as William Maclure's work, *A Map of the United States, Colored Geologically* (1809), but in spite of the title these maps covered only the eastern part of the country. *Gray's Geological Map of the United States*, by Charles H. Hitchcock, professor of geology at Dartmouth, was issued in 1876 and is typical of the maps of the time, depicting the geology of the country in broad strokes. The hand-colored Hitchcock map shows the Cascades as volcanic, the Willamette Valley and the coastline as Tertiary, some Cretaceous rocks in the Klamaths and southeastern Oregon, and the remainder of Oregon (Coast Range, eastern Oregon, Klamaths) as "Eozoic," that is, pre-Silurian. From the 1850s to after 1870, the first regional geologic maps of the Pacific states included only areas of California and a number of profiles of Vancouver Island.

Most of the early maps, if they showed Oregon at all, were concerned with the Coast Range only. Then, in 1906, Ellen Condon McCornack contributed *A Student's Geological Map of Oregon, With Notes*, the first complete geologic map on which Oregon is not part of a larger geographic unit. The 25 pages of text provide a summary of Oregon's geologic history. On the map, the geology, from pre-Cretaceous through Pleistocene, is not colored but depicted by patterns. In drawing up the map, McCornack was able to rely on publications by Condon, Diller, and Russell, and on the work of another USGS geologist, W. Lindgren, who contributed the report, "The Gold Belt of the Blue Mountains of Oregon," to the USGS Annual Report of 1901.

Diller's publishing record was nearly matched by that of Edward Drinker Cope, vertebrate paleontologist, whose work focused on the John Day and Great Basin regions. His 1,000-page *Vertebrata of the Tertiary Formations of the West* appeared as an 1883 monograph from the Hayden survey, and "The Silver Lake of Oregon" (1889) described Oregon fossils in the *American Naturalist*, where his first discussion of John Day fossils was published in 1873. Cope often collected fossils under difficult conditions. At one point Cope was conducting his field work with a team of four mules and a wagon and was reduced to eating bacon, stewed tomatoes, and crumbled biscuits, even feasting on cold canned tomatoes for breakfast.



View looking north from Forest Grove, Washington County. Illustration from "A Geological Reconnaissance in Northwestern Oregon," by J.S. Diller, published in U.S. Geological Survey 17th Annual Report, *1896.*

Eventually, another overview of Oregon geology was synthesized, this time by two geologists of the University of Oregon, Warren DuPré Smith, a field geologist, and Earl L. Packard, a paleontologist. "Salient Features of the Geology of Oregon" was issued in 1919 as an article in the *Journal of Geology* and as a University of Oregon *Bulletin*. This short account of 42 pages takes "an inventory of our knowledge" of Oregon geology, presenting it in a fairly technical manner. Most of the text deals with stratigraphy, although there is a short section on the geologic history and economics of the state. Smith, serving as chairman of the Geology Department some time after Thomas Condon, received numerous requests for copies of the publication, which was not distributed commercially but which he sent out without charge.

Classic papers on Oregon's geology concluded this early period: Ira A. Williams' *The Columbia River Gorge: Its Geologic History*, with outstanding photographs, appeared in 1916. It was soon followed by J. Harlen Bretz' controversial papers, "The Channeled Scablands of the Columbia Plateau" (1923) and "The Spokane Flood Beyond the Channeled Scablands" (1925). Geologists dismissed Bretz' ideas and were slow to accept the notion of large-scale floods.

FOLLOWING DECADES

Geological sciences in the state took several steps forward in the 1930s. The first of these occurred with the beginning of the school year in 1932, when a new department of science at the State College in Corvallis began to train students in geology. A shy, well-known paleontologist, Earl L. Packard, was the reluctant dean of the new science school. Prior to this time, geology classes had been taught at Corvallis by the School of Mines. In 1932, the School of Geology, along with other science departments, was transferred from the University of Oregon at Eugene to Corvallis, where all science programs were combined. The purpose of the reorganization was to reduce duplication in class offerings during times of financial stress. The decision was based on recommendations made after a survey of Oregon higher education had been conducted. In the sciences, the major argument soon emerged over the issue of which school should offer "pure" science as opposed to "applied" science.

As a result of this arrangement, 86 sets of science journals were moved from the University of Oregon to the library at Corvallis. These books were never fully processed at the State College, and the transfer of books ceased in 1933, when O.F. Stafford, University of Oregon librarian and Dean Packard's official representative at the University of Oregon, refused to allow Beilstein's *Handbook of Organic Chemistry* to be moved from the Eugene campus. After a decade of unhappiness, protest, and conflict, the State Board of Higher Education restored the natural sciences to Eugene in 1942.

Yet another milestone was reached in 1937 with the initiation of a State geology department. Some years earlier, in 1911, the State Legislature had created a State department of geology, nearly 40 years after Thomas Condon's appointment as the first State Geologist. This "Oregon Bureau of Mines and Geology" was first incorporated into the Oregon Agricultural College at Corvallis; beset with financial and administrative problems, however, the Bureau disbanded in 1923. In spite of these troubles, the Bureau had contributed significantly to the geologic literature by issuing bulletins, short papers, maps, and miscellaneous publications.

In an attempt to rectify the situation, the Legislature created the present Department of Geology and Mineral Industries (DOGAMI) in 1937 with a biennial operating budget of $60,000. The new department was also to administer the distribution of an additional $40,000 to encourage placer mining through grubstake loans of $50 a year to any prospector who applied and met the requirements. The Department's first Bulletin in 1937 contained the legislation that established the department and controlled the mining activity in the state. The following year, 1938, ten Bulletins were released. Clyde P. Ross' *The Geology of Part of the Wallowa Mountains* (Bulletin 3) sold for $.50; and Henry C. Dake's *The Gem Minerals of Oregon* (Bulletin 7) for $.10. During 1938, the Department also issued the monthly *Press Bulletin*, which was replaced a year later by the *ORE.-BIN* (spelled thus, until both spelling and format were changed in 1962) and was sent free to libraries, universities, colleges, and legislators. Earl K. Nixon, first Director of the department, stated that the purpose of the publication was "to advise the public of the work of the Department and of new and interesting developments in mining, metallurgy, and geology." In 1979, the *Ore Bin* became *Oregon Geology*, the title reflecting a change in emphasis in the geology of the state in more recent years.

Milestones of geologic exploration from this time were Howel Williams' *The Ancient Volcanoes of Oregon* and Ralph W. Chaney's *The Ancient Forests of Oregon* (both 1948). They represented the culmination of many years of work in Oregon. Chaney, a significant force in Oregon paleobotany for decades, wrote and published extensively in the state until his death in 1971 at the age of 81 years.

Ewart M. Baldwin, a professor of geology at the University of Oregon, was another geologist who worked and published extensively in the state. The first edition of his *Geology of Oregon* appeared in 1959, just 57 years after Condon's synthesis of Oregon geology. As it had been with Condon, Baldwin had lived in Oregon for a number of years and was faced with the task of gathering and compiling information from an overwhelming number of sources. His first edition, written in a nontechnical manner, was "concerned mainly with the historical geology of Oregon." The initial edition of Baldwin's book was issued and distributed by the University of Oregon bookstore and sold for about $2.

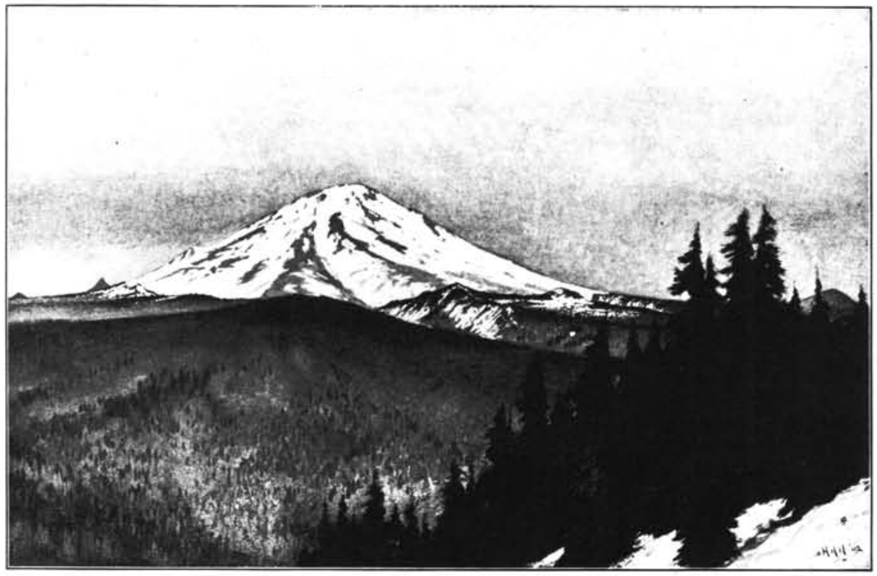
Since the late 1960s and continuing to the present, the theories of continental drift and plate tectonics have had great impact on geologic research and literature in Oregon. Gaining acceptance only after years of controversy, continental drift theory was synthesized in 1960 by Harry Hess of Princeton University, who compiled facts about the creation and movement of the sea floor in a hypothesis that he called "geopoetry."

From that point forward, the concept of plate tectonics took almost 10 years to cross the continent to the West Coast, where it was ushered in with Robert Dott's "Circum-Pacific Late Cenozoic Structural Rejuvenation—Implications for Sea Floor Spreading" of 1969. Dott briefly reported on the "widely acclaimed hypothesis of sea floor spreading, and especially its latest refinement, the lithosphere plate hypothesis," touching briefly on its impact in Oregon. He felt, rightly enough, that these "rare simplifying generalizations of knowledge [will] provide powerful new bases for formulating and rapidly testing questions about the earth." In 1970, Tanya Atwater published her extensive study "Implications of Plate Tectonics for the Cenozoic Tectonic Evolution of Western North America." As knowledge of tectonics expanded, the theory that much of the western margin of North America was made up of accreted terranes was supported by D.L. Jones, N.J. Silberling, and J. Hillhouse in "Wrangellia—a Displaced Terrane in Northwestern North America" (1977) and W.P. Irwin's "Ophiolitic Terranes of California, Oregon, and Nevada" (1978).

As early as 1965, before plate tectonics or accretion theories had been fully accepted, W.R. Dickinson and L.W. Vigrass, in their *Geology of the Suplee-Izee Area, Crook, Grant, and Harney Counties, Oregon*, puzzled over the geology of central Oregon. These problems were readily explained in the 1978 paper, "Paleogeographic and Paleotectonic Implications of Mesozoic Stratigraphy and Structure in the John Day Inlier of Central Oregon," by W.R. Dickinson and T.P. Thayer. The 1978 paper by H.C. Brooks and T.L. Vallier, "Mesozoic Rocks and Tectonic Evolution of Eastern Oregon and Western Idaho," summarized the tectonic knowledge of the Blue Mountains at this point.

Cascadia, the Geologic Evolution of the Pacific Northwest, appeared in 1972. The author, versatile E. Bates McKee, pilot, hockey player, and yachtsman as well as geologist, began teaching at the University of Washington in 1958. Energetic and enthusiastic, McKee gathered together the material for his book, taking sabbatical leave from 1970 to 1971 in order to complete the manuscript. McKee died in 1982 in a plane crash while doing field work in the Cascades. *Cascadia* was written for the layman, student, and geologist to provide "an introduction to the evolution of the Northwest landscape." The geology of Oregon is included along with that of Washington, British Columbia, and parts of Idaho; consequently, some of the geologic details are cursory because such a wide region is covered.

Notable regional compilations in these decades focused on the Cascades and western Oregon. The classic paper by Dallas L. Peck and others, *Geology of the Central and Northern Parts of the Western Cascade Range in Oregon* (1964) was supplemented by *Geology and Geothermal Resources of the Central Oregon Cascade Range* of 1983, edited by G.R. Priest and B.F. Vogt. Geologists P.D. Snavely, Jr., and H.C. Wagner summarized the *Tertiary Geologic History of Western Oregon and Washington* in 1963. John E. Allen's book, *The Magnificent Gateway*, a geologic guide to the Columbia River, was issued in 1979.



"Mount Mazama restored," as J.S. Diller presumed it would have looked in his time, had it not erupted. Illustration from Diller's 1902 study of Crater Lake National Park, U.S. Geological Survey Professional Paper 3.

Other significant contributions to the expanding knowledge of Oregon's geology were the book *Mineral and Water Resources of Oregon* of 1969, prepared by the U.S. Geological Survey in cooperation with DOGAMI; and the *Handbook of Oregon Plant and Animal Fossils* (1981) by William N. and Elizabeth L. Orr, which collected all of the paleontological material for the state under one title. Two further additions were the state geologic map and the chart produced in the nationwide COSUNA project: *Geologic Map of Oregon West of the 121st Meridian* (1961), by Francis G. Wells and Dallas L. Peck; its companion piece, *Geologic Map of Oregon East of the 121st Meridian* (1977), by George W. Walker; and the *Correlation of Stratigraphic Units of North America, Northwest Region* (1988), a compilation of regional stratigraphy. [The two halves of the state geologic map have now been replaced by a one-piece, complete *Geologic Map of Oregon* (1991). See announcement elsewhere in this issue. —ed.]

GEOLOGIC LITERATURE ON OREGON

The first bibliography of Oregon geology was the *Bibliography of the Geology, Paleontology, Mineralogy, Petrology, and Mineral Resources of Oregon*, compiled by C. Henderson and J. Winstanley and published in 1912. The number of articles listed in this bibliography reflects the interest generated by the early explorations that had opened Oregon to a multitude of geologic workers. A review of the citations in the bibliography shows clearly that the early publications gave sweeping overviews of the region, whereas the studies after the 1870s narrowed their subject matter to more localized topics. The majority of publications during this period focused on paleontology, followed by those on physiographic features.

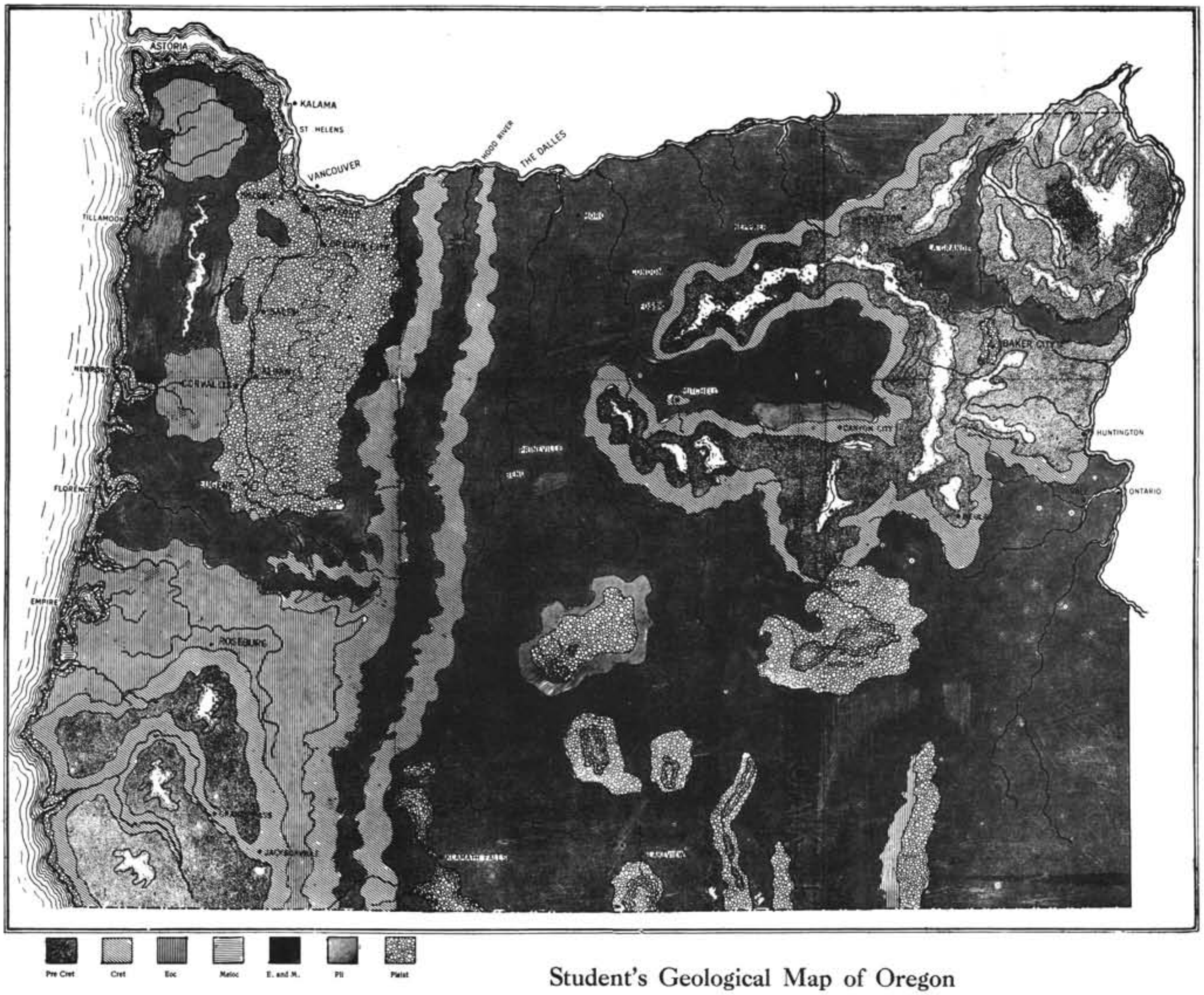
In 1936, R.C. Treasher and E.T. Hodge produced the *Bibliography of the Geology and Mineral Resources of Oregon*, which appeared just a decade after D.E. Dixon's 1926 *Bibliography of the Geology of Oregon*. Examination of all three bibliographies shows a striking increase in the number of articles on Oregon geology: Treasher and Hodge list 2,155 publications, as compared to Dixon's 1,065 and Henderson and Winstanley's 493 items.

In the bibliographies of 1926 and 1936, publications on mines and minerals, followed by those on paleontology and regional topics, constituted the bulk of geologic literature. During these decades the emphasis was definitely on economic geology. Gold was treated in 302 articles, coal in 110, copper in 98, and iron in 91. This interest is also reflected in the number of publications dealing with counties that have a high amount of mining activity, such as Baker County (118), Klamath County (92), Josephine County (81), and Jackson County (79), whereas Lane County appeared in only 17 publications and Multnomah County in 9. Individual paleontologists were the most prolific researchers, led by John C. Merriam, who produced 44 papers on vertebrate paleontology, and Ralph W. Chaney, who published 28 studies on paleobotany.

From 1940 to 1960, the subject matter of geologic literature again showed gradually changing trends. The preponderance, as shown in the literature, was on minerals, secondly on rock formations and regional areas, while the number of papers on paleontology declined. A total of 2,069 papers was listed in the several supplements to the 1936 bibliography that were published by DOGAMI. The emphasis was still on the mining industry in both geologic literature and research, with 77 articles on gold, 78 on chromite, and a surge of papers on oil and gas (113), most of them produced by DOGAMI. The counties most often cited in the literature were Clackamas, Lake, Lane, Lincoln, Douglas, Baker, and Grant—areas that were being closely examined for their economic resource potential as well as surveyed for regional geologic data. Thus, for example, Lincoln County was reviewed for fossil localities, landslide hazards, coastal geology, agates, and a variety of minor subjects. By the end of the 1950s, research in fields of Oregon geology was becoming more diversified. Ground water, volcanology, structural geology, and petrology were expanding fields of study.

Topics in geologic literature were spread fairly evenly over broad areas from the 1960s to the 1980s. Approximately 975 citations were on geologic formations, 850 on areas of regional interest, 735 on minerals, 563 on paleontology, 334 on ground water, 286 on geomorphology, 260 on structure, 250 on volcanology, 235 on tectonics, and 199 on petrology. The total number of papers on geology of Oregon listed in the *Bibliography of the Geology and Mineral Resources of Oregon* supplements was 4,549 for the 20-year period.

Areas generating the most interest were in eastern and southern Oregon: Malheur (160), Grant (117), and Harney (121) Counties in the east and southeast; Klamath (118) and Lake (146) Counties in the south; and Coos (111) and Curry (130) Counties on the coast. Much of the activity was in regional mapping and in studies of the structure, stratigraphy, mineral resources, and paleontology. Volcan-



First geologic map exclusively of Oregon: A Student's Geological Map of Oregon, with Notes, *by Ellen Condon McCornack, 1906.*

ism ranked high as a field of study during the period. In evidence of this interest, 227 citations were devoted to the Columbia River basalts, followed by 101 on the John Day Formation, and 78 on the Clarno Formation. Coastal regions were examined for mineral resources, coastal processes, paleontology, and stratigraphy.

After 1980, research was further refined into narrow categories such as tectonophysics, strontium isotopes, clay mineralogy, diagenesis, and organic materials. However, the lines between the individual fields became blurred with the development of interdisciplinary fields of research. Delineation of formations (1,145) led in citations in the literature, followed by economic geology (994), regional topics (779), volcanology (622), paleontology (540), and ground water (471). The number of papers on aspects of tectonics doubled after 1980. The total number of publications for the period from 1980 to 1990 was 2,244.

It is interesting to note that research focused on the same counties as earlier (1960-1980), with the exception of Deschutes County, where intensive explorations at Newberry Crater contributed significant data. Malheur County studies showed a preponderance of articles on the McDermitt caldera; in Klamath County, hydrogeothermal exploration and study of Crater Lake dominated; whereas in Lake County, volcanism, mineral resources, and some geothermal research accounted for the emphasis. Several geologic maps as well as maps of mineral resources were produced on Curry County.

Finding solutions to the geologic problems faced today is really no more difficult than in the past. In recent years, the focus has been on seismicity and earthquake hazards, geothermal research, economic resources, and environmental concerns. The geologic literature will reflect these trends as they continue to mature.

ACKNOWLEDGMENTS

The authors would like to thank Ewart Baldwin, Richard Heinzkill, Carol McKillip, and Lloyd Staples of the University of Oregon for reading the manuscript and giving suggestions.

SUGGESTED FURTHER READING

An extensive bibliography will be included in the upcoming book mentioned at the beginning of this article.

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The Mount Angel fault: Implications of seismic-reflection data and the Woodburn, Oregon, earthquake sequence of August 1990

by K. Werner[1], J. Nábelek[2], R. Yeats[1], and S. Malone[3]

INTRODUCTION

The Mount Angel fault is part of the northwest-trending Gales Creek-Mount Angel structural zone (Beeson and others, 1985) that extends across much of northwestern Oregon (Figure 1). On the basis of water-well data and outcropping Columbia River basalt (Figure 2), Hampton (1972) originally mapped the Mount Angel fault in the northern Willamette Valley from the edge of the Waldo Hills to just northwest of the city of Mount Angel. By incorporating commercial seismic-reflection data, we can now extend the fault northwestward to Woodburn. The southeastern extent of the fault is poorly constrained due to poor exposure in the Waldo Hills. However, the fault may continue into the Western Cascades, where it appears to have formed a barrier to three of four Silver Falls flows of the Miocene Columbia River basalt (Beeson and others, 1989). In addition, a Ginkgo intracanyon flow of the Columbia River basalt is dextrally offset approximately 1 km across the fault due to faulting or a sharp jog in the canyon (M. Beeson, personal communication, 1989).

The following discussion of the geologic structure of the Mount Angel fault is largely based on the interpretation of seismic-reflection data in the northern Willamette Valley. The seismic-reflection data are tied to a synthetic seismogram of the DeShazer 13-22 petroleum exploratory well (Werner, 1991). Recent seismicity near Woodburn was probably related to the Mount Angel fault and suggests that the fault is active.

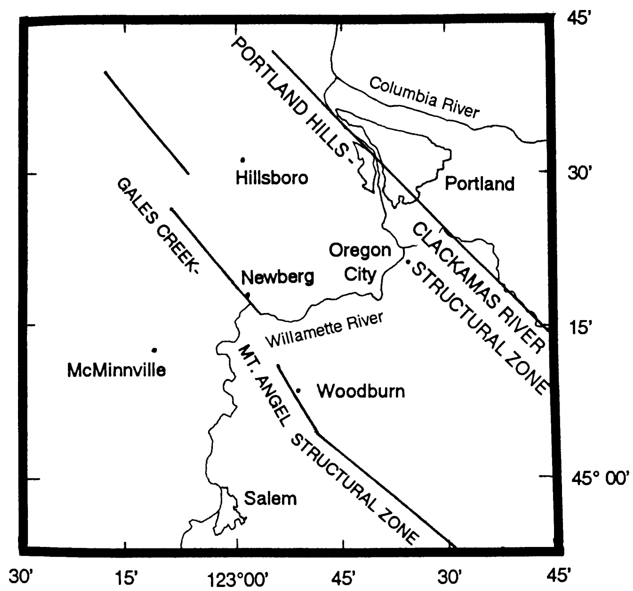

Figure 1. Map showing the Gales Creek-Mount Angel structural zone and Portland Hills-Clackamas River structural zone.

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Table 1. *Woodburn seismicity*

Earthquake	Latitude	Longitude	Date	Magnitude
1	45.133	-122.886	7/3/80	1.7
2	45.142	-122.874	8/20/83	1.2
3	45.165	-122.871	9/9/83	1.6
4	45.153	-122.847	8/14/90	2.0
5	45.113	-122.877	8/14/90	2.5
6	45.118	-122.860	8/22/90	2.4
7	45.132	-122.867	8/22/90	2.2
8	45.120	-122.871	8/23/90	2.4
9	45.107	-122.866	8/23/90	1.4

GEOLOGIC EVIDENCE FOR THE MOUNT ANGEL FAULT

The Mount Angel fault vertically offsets Columbia River basalt and younger sedimentary strata down to the southwest as shown on two seismic-reflection lines and one water-well cross section located in the southeastern portion of the northern Willamette Valley (Figure 3). No vertical offset is evident on the east-west seismic-reflection line that goes through Hubbard (Figure 2). The amount of vertical offset of the top of Columbia River basalt increases to the southeast of Woodburn. The vertical offset is approximately 100 m on seismic section A-A′ (Figure 4), 200 m on seismic section B-B′ (Figure 5), and 250+ m on cross section C-C′ (Figure 6). The amount of offset calculated for cross sections A-A′ and B-B′ is based on average velocities (determined from depths in wells and the corresponding two-way travel time on seismic-reflection lines [Werner, 1991]) and stacking velocities, both of which are in general agreement.

The 250+ m of separation on cross section C-C′ is based on the difference in altitude between the top of Columbia River basalt in a water well and the altitude of Mount Angel (Figure 6). Mount Angel has an elevation of 85 m above the valley floor and is composed of both Grande Ronde Basalt and the younger Frenchman Springs Member of the Columbia River Basalt Group (M. Beeson, personal communication, 1990). The presence of the Frenchman Springs Member at the top of Mount Angel indicates that little of the Columbia River basalt section has been eroded, so the displacement is probably not much more than 250 m. The 250+ m offset determined at Mount Angel may not represent the vertical slip across the entire Mount Angel fault zone. Because of the steep northeast side of Mount Angel, the topographic high of Mount Angel (and the adjacent Columbia River basalt exposure to the northwest) may be caused by a positive flower or pop-up structure as shown in Figure 7.

The dip of the Mount Angel fault is poorly constrained; furthermore, the fault probably consists of several splays with different dips. Due to the poor constraint on dip, seismic reflectors could have a reverse or normal sense of offset. The best constraints

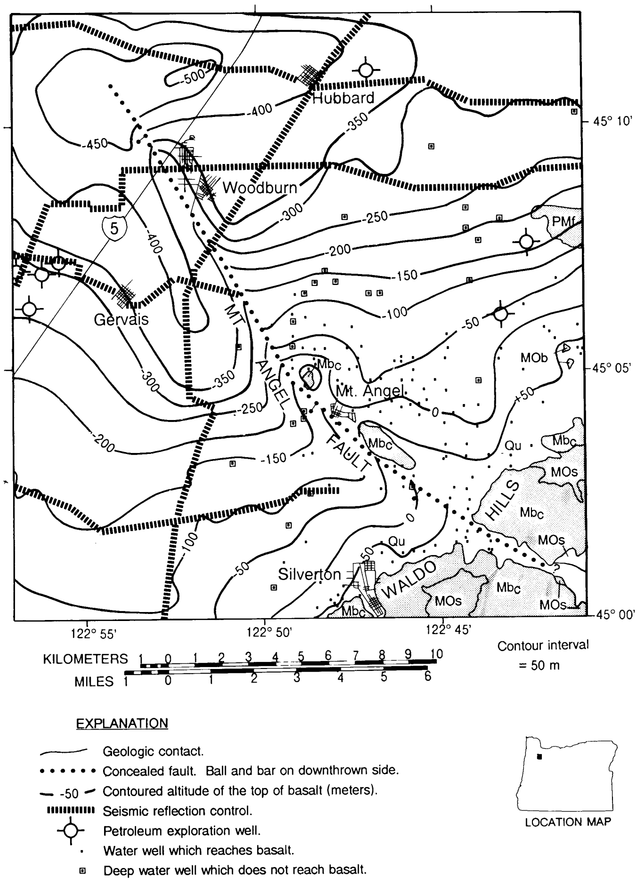

Figure 2. Contour map on the top of basalt, which is primarily Columbia River basalt except near outcropping MOb. Geologic units are labeled as follows: Qu = Quaternary undifferentiated sediment; PMf = Pliocene and Miocene fluvial and lacustrine sediments; Mb_C = Miocene Columbia River basalt; MOs = Miocene and Oligocene sedimentary rock; MOb = Miocene and Oligocene basalt.

on the sense of offset and near-surface dip of the fault are offset reflectors present on seismic line B-B′ (Figure 5). On the basis of the offset reflectors, the near-surface portion of the Mount Angel fault (or this splay of the fault) appears to have an apparent reverse offset and dips approximately 65° to the northeast.

Progressive displacement occurred on the Mount Angel fault as shown by differentially offset reflectors. The top of Columbia River basalt is offset 200 m along seismic section B-B′, while an overlying reflector in Pliocene and Miocene fluvial and lacustrine sediments appears to be vertically separated 41 to 96 m (depending on which reflectors are matched across the fault). We prefer the reflector offset shown in Figure 5, an offset of 96 m. Seismic line resolution is inadequate to determine if the fault deforms younger sediments.

Deformation associated with the Mount Angel fault appears to have occurred both before and during (or after) deposition of Pliocene to Miocene sediments. An angular unconformity at the base of Pliocene and Miocene sediments indicates pre-sediment deformation. Onlapping Pliocene and Miocene sediment reflectors are themselves warped into a syncline (structural relief on one reflector in Pliocene and Miocene sediments is approximately 45 m) due to continued deformation during or after their deposition (Figures 4 and 5).

RELATIVE MOTION ALONG THE MOUNT ANGEL AND GALES CREEK FAULTS

The Gales Creek and Mount Angel faults comprise a major northwest-trending linear structural zone more than 150 km long (Figure 1) (Beeson and others, 1985, 1989). The structural zone appears to consist of en echelon faults rather than one continuous fault. Both vertical and horizontal separations are evident along the Gales Creek and Mount Angel faults. Mumford (1988) noted approximately 200 m of vertical separation along the Gales Creek fault in southeast Clatsop County. Similarly, seismic lines as well as the topographic high of Mount Angel indicate 100 to more than 250 m of vertical separation (northeast side up) along the Mount Angel fault in the Mount Angel area.

The vertical separation across the Mount Angel fault is probably a result of local compression (extension is possible but less likely) across the fault zone. It does not appear to be related to strike-slip motion. The vertical separation is not due to dextral strike-slip motion, because the Columbia River basalt is generally dipping northeastward in the Mount Angel area (Figure 2), and dextral strike-slip motion would serve to counteract uplift on the northeast side of the fault. Sinistral strike-slip motion would be consistent with the differential vertical offset observed; however, it would be inconsistent with relative motion along similarly oriented faults and inconsistent with the current north-south direction of horizontal maximum compression determined from borehole breakouts and seismicity in western Oregon (Werner and others, 1991).

Although dip-slip motion appears to be important locally along the Mount Angel fault, right-lateral motion has probably been more important in forming the Gales Creek-Mount Angel structural zone. Along the Gales Creek fault, Mumford (1988) inferred right-

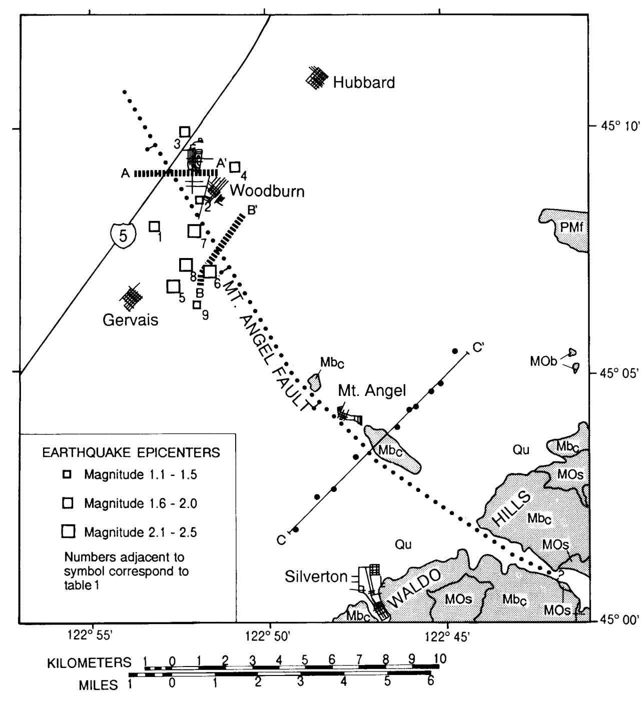

Figure 3. Epicenters of earthquakes near the Mount Angel fault and location of seismic and water-well cross sections. Number corresponding to each earthquake refers to Table 1. Geologic units as in Figure 2.

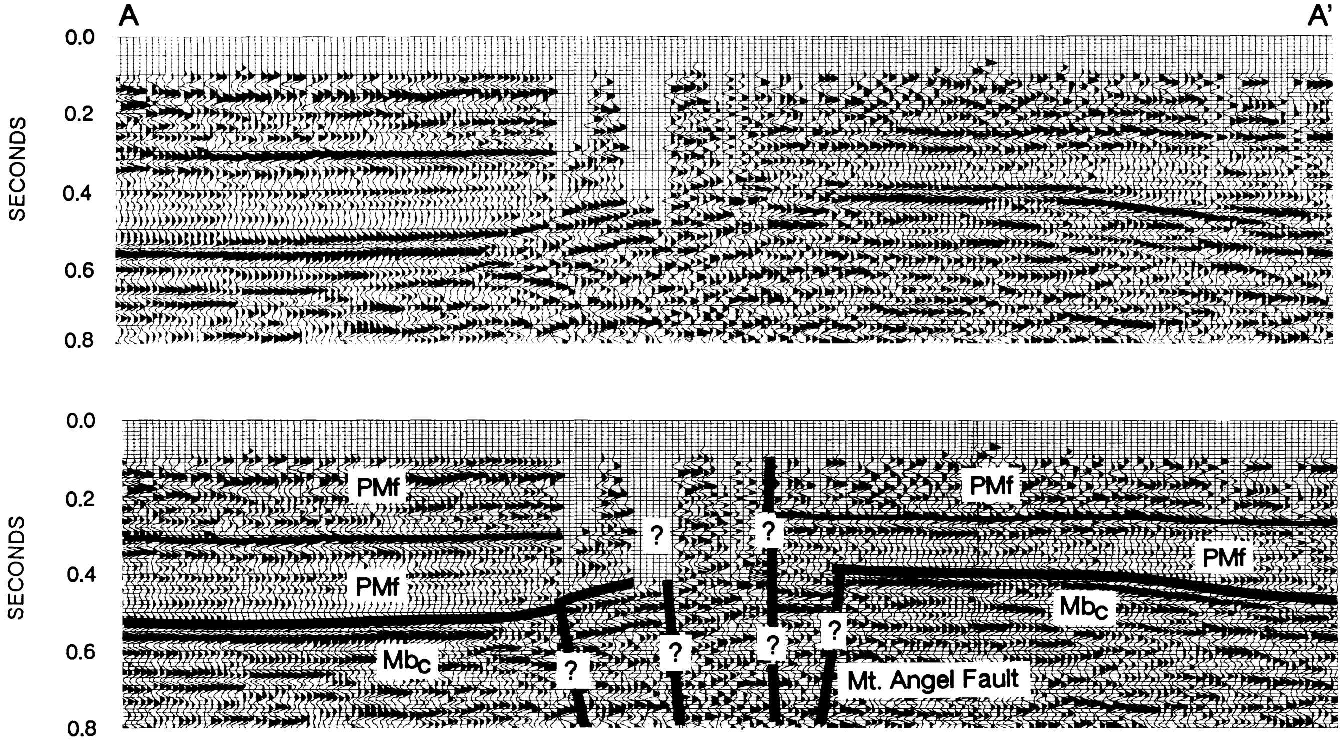

Figure 4. Seismic section A-A′ across Mount Angel fault. Location shown in Figure 3; geologic units as in Figure 2. Because fault is difficult to locate due, in part, to data gaps and may consist of more than one splay, it is shown to be vertical. Note greater vertical separation of top of Mb_c than of reflector within PMf.

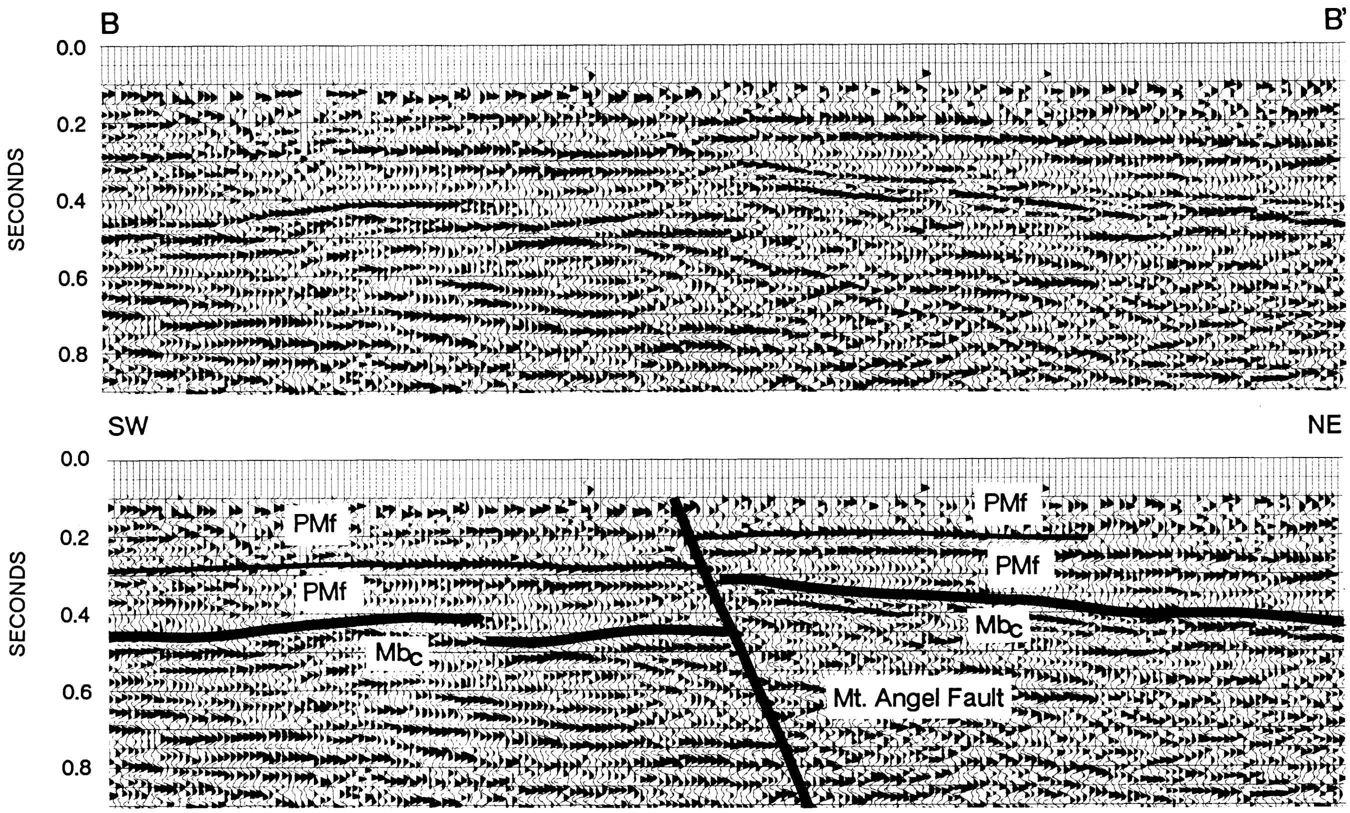

Figure 5. Seismic section B-B′ across Mount Angel fault. Location shown in Figure 3; geologic units as in Figure 2. Fault appears to have reverse separation and to dip northeast. Note greater vertical separation of top of Mb_c than of reflector within PMf.

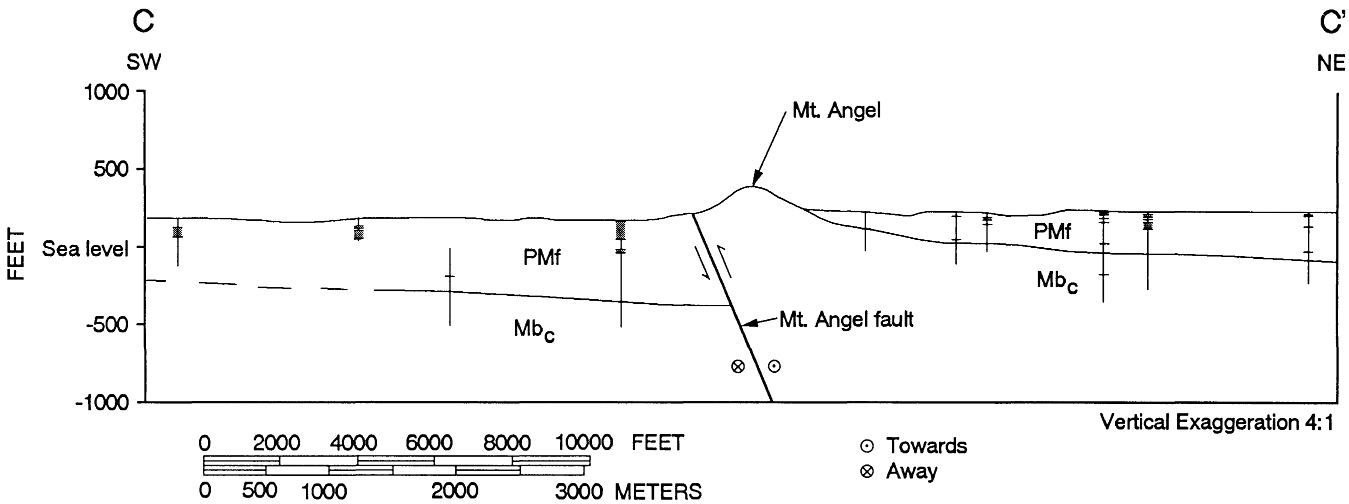

Figure 6. Structural cross section C-C′ of the Mount Angel fault, based on water wells. Location of cross section and constraining water wells shown in Figure 3; geologic units as in Figure 2. A few wells were located on the basis of information from farmers or drillers of Staco Well Services. Only those intervals of wells that were logged are shown. The near-surface dip of the fault is interpretive and based on cross section B-B′. The base of Mb$_C$ is unconstrained. Conglomerate intervals are indicated by two horizontal lines with shading between them. Very thin conglomerate lenses are shown by a horizontal line.

lateral motion from offset northeast-trending faults, and Safley (1989) noted a 2-m-thick gouge zone and slickenside surface. The slickenside surface indicates right-lateral oblique-slip motion; the rake of the slickensides is 25° SE. Similarly, motion along the Mount Angel fault has probably been largely right-lateral, because of its similar orientation to the Gales Creek fault, the linearity of the zone, a possible 1-km dextral offset of the Miocene Ginkgo intracanyon flow, and the current north-south direction of maximum horizontal compression.

SEISMICITY

On August 14, 22, and 23, 1990, a series of six small earthquakes with coda magnitudes (m_c) of 2.0, 2.5, 2.4, 2.2, 2.4, and 1.4 occurred with epicenters near Woodburn (Figure 3, Table 1). The epicenters also correspond to the northwestern end of the Mount Angel fault. Epicentral errors for these events are about ±2 km. In 1980 and 1983, three events with $m_c \leq 1.7$ also occurred in this locality (Figure 3, Table 1).

Initial routine locations by the Washington Regional Seismograph Network (WRSN) for the August 1990 events indicated a hypocenter depth of about 30 km (±5 km). However, wave-form modeling indicates a substantially shallower hypocenter depth of 15-20 km. The routine hypocenter determination made by WRSN might have been biased by an inappropriate structure (for Oregon, WRSN routinely uses a structure based on a refraction line in the Cascade graben) and inadequate station coverage (the nearest station was 60 km from the epicenter). Relocating the earthquake by using a structure for western Washington shifts the hypocenter estimates to 20-25 km, in much better agreement with waveform modeling.

The August 1990 series of events was recorded by the IRIS/OSU broadband seismic station in Corvallis (COR; epicentral distance 68 km) as well as the WRSN. For all events, the wave forms recorded at any given station are remarkably similar (Figure 8), indicating essentially identical locations and mechanisms. Two alternative focal mechanisms, constrained by wave-form modeling of Corvallis station (COR) seismograms and first-motion data, are shown in Figure 9. A range of solutions between the solid and dashed focal mechanisms would satisfy the data. The solutions were determined by means of a coarse grid search, i.e., varying strike from 320° to 360°, dip from 70° to 110°, and rake of the slip

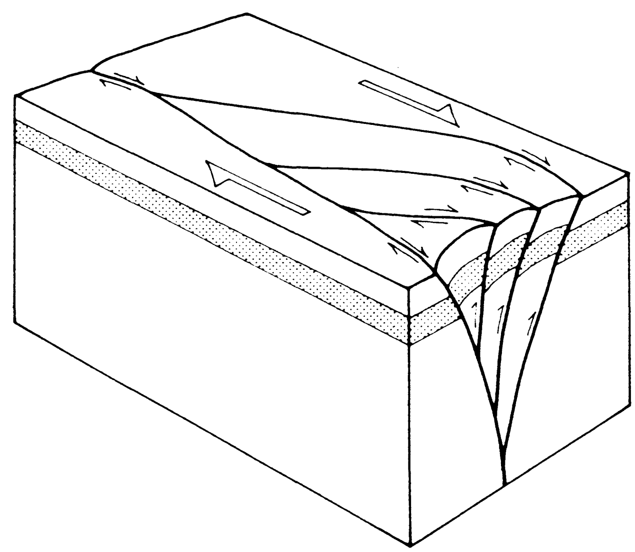

Figure 7. Schematic three-dimensional model of a Mount Angel pop-up structure from Woodcock and Fischer (1986). The number of splays shown does not necessarily correspond to the Mount Angel fault.

angle from 140° to 220°, all by 10° intervals. The preferred focal-plane solution, the one that results in the closest match between the forward-modeled seismogram and the actual seismogram, is shown by the dashed lines. It is a right-lateral strike-slip fault with a small normal component on a plane striking north-south and dipping steeply to the east. The strike indicated by the preferred focal mechanism solution is somewhat more northerly than the surface-fault strike, based on seismic-reflection data, and shows a slight normal component of slip—contrary to seismic reflection data that appear to show that since the Miocene, on average, the motion on the Mount Angel fault has had a thrust component. However, a pure strike-slip mechanism for the earthquakes is acceptable by our data.

The location and focal mechanisms of the earthquakes indicate that the quakes are probably occurring on a deep extension of the

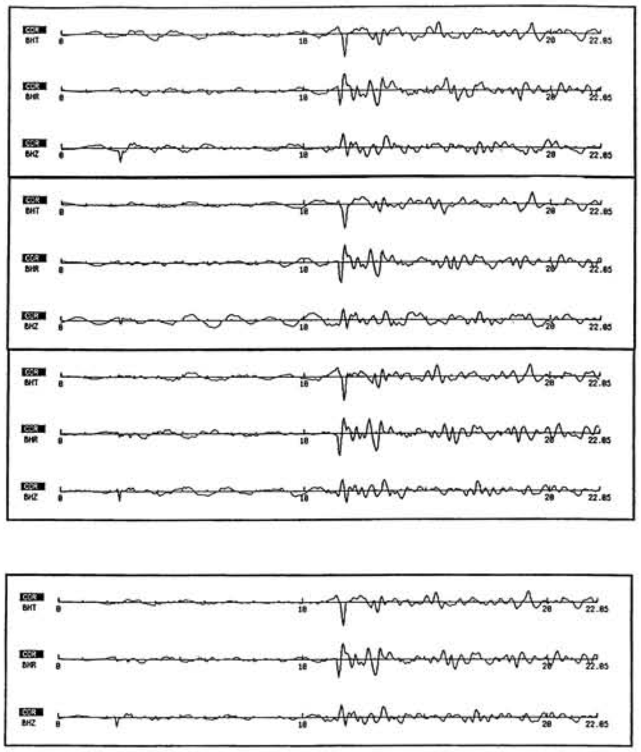

Figure 8. Top three sets of seismograms are displacement records from Corvallis for the largest three events of the Woodburn earthquake sequence. The peaks and troughs of the prominent phases of the three events align to within the digitizing interval (20 samps/s) of the records, which indicates that the events occurred essentially at the same spot. The bottom set of records is the sum of the three individual traces. The signal-to-noise ratio at the longer periods is improved.

Mount Angel fault. Although the association between the earthquakes and the surface fault is somewhat tentative due to the depth of the earthquakes, the tectonic stress implied by both is consistent.

TECTONIC IMPLICATIONS

The trend and sense of motion of the Gales Creek-Mount Angel structural zone are similar to those of the Portland Hills-Clackamas River structural zone in the Portland area (Figure 1). The Portland Hills-Clackamas River structural zone is a major structural feature consisting of faults and folds generated in response to dextral movement (Beeson and others, 1989). Recent seismicity, including a M_w=5.1 earthquake on November 6, 1962, with its epicenter in the Portland area and a swarm of small earthquakes in October 1991, appears to be related to motion along the Portland Hills-Clackamas structural zone (Yelin and Patton, 1991). Together, the Gales Creek-Mount Angel and Portland Hills-Clackamas River structural zones may take up dextral shear imposed on the upper plate by oblique subduction of the Juan de Fuca Plate beneath the North American Plate.

Dextral shear has been noted by Wells and Heller (1988) and Wells (1990) as an important mechanism for generating rotation observed in paleomagnetic results. Wells and Heller (1988) conclude that dextral shear is responsible for about 40 percent of post-15-Ma rotation. Coastal sites of 15-Ma flows of Grande Ronde Basalt show an average rotation of 22° clockwise when compared to sites on the Columbia River Plateau; rotation decreases from the coast eastward (Wells and Heller, 1988). Tectonic models explaining the paleomagnetic results have varied from rotation of a single Coast Range block to distributed shear on many smaller

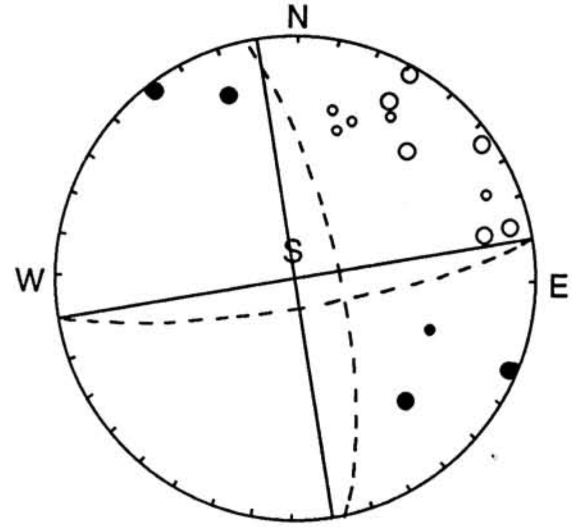

Figure 9. Two possible composite focal mechanisms for the six August 1990 earthquakes near Woodburn. Open circles indicate dilatation at a given station; solid circles indicate compression. Larger circles indicate a stronger first motion.

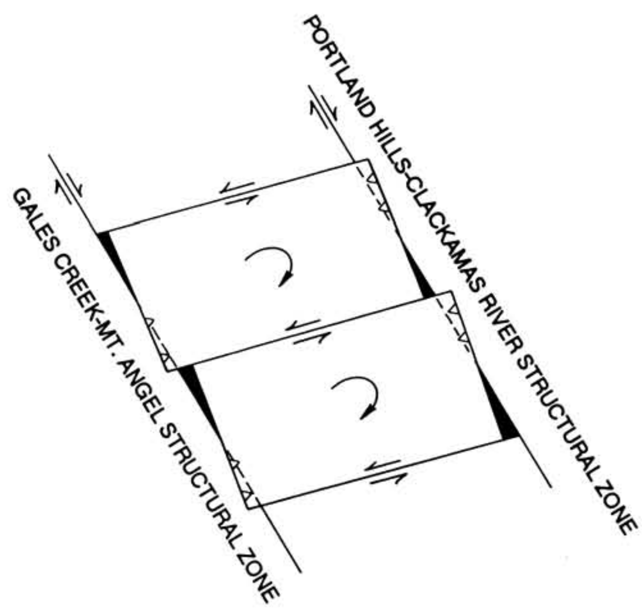

Figure 10. Model for block rotation between the Gales Creek-Mount Angel structural zone and Portland Hills-Clackamas River structural zone. It is based on a model applied to rotation of blocks near the intersection of the San Andreas and San Jacinto faults, California, by Christie-Blick and Biddle (1985).

faults (Sheriff, 1984; Wells and Heller, 1988). Wells and Heller (1988) argue that the tectonic processes responsible for rotation are operating on an intermediate scale (10^2-10^4 m). Such a scale is consistent with the model of rotation shown in Figure 10 (after Christie-Blick and Biddle, 1985) between the Portland Hills-Clackamas River and Gales Creek-Mount Angel structural zones. Wells and Coe (1985) demonstrate rotation in southwestern Washington along similar major dextral north-northwest-trending faults and west-northwest-trending sinistral R′ riedel shears.

Rotation of intermediate-sized blocks leads to space problems and differential local compression and extension along shear zones as shown in Figure 10. The differential compression associated with rotation could in turn explain the different amounts of vertical separation along the Mount Angel fault.

The Gales Creek-Mount Angel structural zone appears to have been active from Columbia River basalt time to possibly the present. Motion on the Mount Angel fault during the middle Miocene resulted in the formation of a barrier by the time the Silver Falls flows were extruded. Warping and offset of Pliocene and Miocene sediments indicate that deformation continued during the Neogene. The Gales Creek-Mount Angel structural zone may presently be active, if the August 1990 seismicity indeed occurred on a deep extension of the Mount Angel fault.

CONCLUSIONS

According to water-well and seismic-reflection data, the Mount Angel fault extends from the town of Mount Angel north-northwestward to Woodburn. Locally, the fault vertically offsets the top of Columbia River basalt up to 250+ m and appears to offset a reflector corresponding to Pliocene and Miocene fluvial and lacustrine sediments by 96 m. Structural relief on the Pliocene and Miocene fluvial and lacustrine sediments, which form a syncline along the south side of the fault, is 45 m.

A series of small earthquakes of m_c=2.0, 2.5, 2.4, 2.2, 2.4, and 1.4 occurred on August 14, 22, and 23, 1990, with epicenters along the northwest end of the Mount Angel fault. Routine locations indicated a depth of about 30 km; however, wave-form modeling indicates a substantially shallower hypocenter depth of 15-20 km. The preferred composite focal mechanism solution is a right-lateral strike-slip fault with a small normal component on a plane striking north and dipping steeply to the west. The locations and focal mechanisms of the earthquakes are consistent with their being on a deep extension of the Mount Angel fault.

The Mount Angel fault is part of the Gales Creek-Mount Angel structural zone, which appears to be taking up dextral shear imposed on the upper plate by subduction of the Juan de Fuca Plate beneath the North American Plate.

ACKNOWLEDGMENTS

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New southeast Oregon geologic map released

Resources of basalt and sand and gravel were identified as economic mineral commodities in the Jonesboro quadrangle in southeastern Oregon. The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a new geologic map of this Owyhee region quadrangle.

Geology and Mineral Resources Map of the Jonesboro Quadrangle, Malheur County, Oregon, by James G. Evans. DOGAMI Geological Map Series GMS-66, two plates (one two-color geologic map, scale 1:24,000, with explanations and brief discussions; and one sheet containing geologic cross sections and geochemical data tables). Price $6.

The Jonesboro quadrangle (like some geographic features of the area) were named after the Jones Ranch that is located on the Malheur River east of Juntura. The quadrangle straddles the river and includes part of the Sperry Creek Wilderness Study Area. The rocks exposed in the quadrangle are predominantly basalts and reflect a volcanic history that dates back to Miocene time, about 16 million years ago. Over the last approximately five million years, the Miocene rocks were faulted, uplifted, and eroded into a fairly gentle landscape with elevations mostly between 4,000 and 5,000 feet.

Production of the map was funded jointly by DOGAMI, the Oregon State Lottery, and the COGEOMAP Program of the U.S. Geological Survey as part of a cooperative effort to map the west half of the 1° by 2° Boise sheet in eastern Oregon.

The new report, DOGAMI map GMS-66, is now available at the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 731-4066. Orders under $50 require prepayment except for credit-card orders. Purchase by mail and over the counter is also possible at the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496. □

Note to our readers

The column **MINERAL EXPLORATION ACTIVITY** will return to its accustomed place in the next issue. □

THESIS ABSTRACTS

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

Physical volcanology of Holocene airfall deposits from Mount Mazama, Crater Lake, Oregon, Simon R. Young, (Ph.D., University of Lancaster, 1990), 307 p.

The 6,845±50 yrs BP caldera-forming eruption of Mount Mazama (Crater Lake, Oregon) was preceded within 200 years by two plinian eruptions producing voluminous airfall deposits followed by lava flows. This study concentrates on these two airfall deposits as well as the complex airfall deposits from the climactic eruption, which are distributed over ~1.7 million km^2 of northwest America.

Tephro-stratigraphic mapping of airfall units throughout south-central Oregon has revealed the presence of five lobes of coarse pumice deposits and two widespread ash units which are important marker horizons. Detailed grainsize data have been generated by sieving and measurement of maximum clast sizes, and these are used to characterize each deposit and as input data for clast dispersal models of plinian airfall eruptions. Geochemical variations between each deposit generally support the models already developed for Mount Mazama, and geochemical techniques have been used to deduce the source of distal "Mazama ash." The role of volatiles in each eruption is reviewed and, along with the rate of vent and conduit erosion, is found to be vital in controlling eruptive evolution.

Deduction of column height and mass eruption rate for various stages during each eruption has been possible through the use of clast dispersal models and, when combined with eruptive velocity and vent and conduit dimensions, has produced a detailed physical model of eruptive development. This has then been linked to field characteristics to provide significant new information about the physical volcanology of plinian airfall eruptions.

Revised volume estimates for the climactic airfall eruption, including distal fine ash, give a volume of ~20 km^3 (dense rock equivalent), with a maximum column height of ~55 km occurring immediately prior to column collapse and ignimbrite generation. This eruption is thus one of the most intense and voluminous ultra-plinian eruptions yet documented.

Island-arc petrogenesis and crustal growth: Examples from Oregon and Alaska, by Lisanne G. Pearcy (Ph.D., Stanford University, 1991), 184 p.

The bulk compositions determined by mass balance of two exposed sections of intraoceanic island-arc crust, the Talkeetna volcanics and Border Ranges ultramafic-mafic complex in south-eastern Alaska and the Canyon Mountain Complex in northeastern Oregon, are basalt (MgO = 11 percent) and probably basaltic andesite (MgO = 8 percent), respectively, with unfractionated REE abundances approximately 10 times chondrite. Simple accretion of arcs such as these cannot generate a LREE-enriched, andesitic, post-Archean continental crust; that requires modification of their bulk compositions by a combination of processes, including (a) delamination of basal cumulates to make the crust less mafic, (b) addition of alkalic magmas and accreted rocks to enrich the average crust in LREE and other lithophile elements, and (c) partial melting of the lower crust combined with delamination of the residue to do both of the above.

The 2- to 3-km-thick ultramafic-to-mafic "transition zone" (TZ) in the Early Permian Canyon Mountain Complex represents the products of mantle melts that crystallized in a nascent island-arc setting. This zone consists of complexly interlayered pyroxene-rich cumulate rocks, with igneous textures and mineralogy pointing to formation by in-situ crystallization and fractionation at 5-10.5 kb (15-30 km depth) under water-poor conditions. Major- and trace-element compositions of clinopyroxene and the order and relative proportions of phases crystallized indicate that parental magmas were primitive island-arc tholeiitic basalts with some similarities to boninites. Variations in clinopyroxene chemistry reveal trace-element heterogeneity in the parental melts, which may be due to either variable source compositions or disequilibrium mantle melting. Magmas entered the TZ in at least three batches, forming crude, large-scale, cyclic units in some locations. During slow cooling, the TZ rocks were apparently deformed and uplifted to near-surface levels.

The entire Canyon Mountain Complex most likely represents incipient arc magmatism in the Olds Ferry terrane. The complex was transferred to the dismembered forearc region (i.e., Baker terrane) by tectonic erosion of the leading edge of the arc crust. It was then uplifted and emplaced within serpentinite-matrix melange along faults lubricated by serpentinite diapirs.

Geology and Petrology of the Mount Jefferson area, High Cascade Range, Oregon, by Richard M. Conrey (Ph.D., Washington State University, 1991, 357 p.

An area of approximately 150 km^2 surrounding Mount Jefferson is underlain by a volcanic field of andesite and dacite composition. The area is thus one of the few places in the High Cascades in Oregon, like Mount Hood, South Sister, and Crater Lake, where intermediate and siliceous rocks are abundant. A complex history of activity during the past 0.7 Ma is preserved at Mount Jefferson; 158 units were mapped. There is no evidence of an underlying "mafic platform" of overlapping basaltic andesite shield volcanoes. Due to the onset of extensive glacial erosion about 0.8 Ma, preservation of older rocks is rare. Exposures of 1.0- to 3.5-Ma andesites and dacites at the margins of the area, however, suggest that andesite and dacite-dominated volcanism around Mount Jefferson may be of several million years duration.

$^{87}Sr/^{86}Sr$ isotopic ratios range from 0.77028 to 0.7036 in mafic and intermediate rocks at Mount Jefferson; ratios in dacites and rhyodacites are nearly constant at 0.7033-0.7034. There is also a significant variation of Pb isotope ratios in mafic and intermediate rocks. The isotope data require the participation of three processes in magma genesis: partial melting of typical suboceanic mantle and mafic lower crust, and either crustal assimilation by mafic magmas or subduction of crustal materials and contamination of the underlying mantle.

Abundant trace-element data rule out crystal fractionation as the dominant petrogenetic mechanism: many incompatible trace elements fail to increase with supposed degree of differentiation. Mineraologic evidence from detailed studies of the youngest andesites and dacites requires mixing of mafic and siliceous magmas. Convective mixing of magmas may account for the uniqueness of phenocrysts in dacites and andesites: chaotic turbulent convection would carry each phenocryst along a different pathway.

Profound differences exist in the mineralogy and chemistry of intermediate and siliceous rocks erupted before and after the development of an intra-arc graben 4-5 Ma in the Cascade Range. Pre-graben dacites and thyodacites were buffered between NNO and QFM, amphibole free, and richer in incompatible trace elements; post-graben siliceous magmas were buffered 1-2 log units above NNO, and are invariably amphibole-bearing gneisses in the middle crust, while the latter were formed by partial melting of garnet-bearing amphibolites in the deep crust. Amphibole was not a near-liquidus phase during mixing of pre-graben mafic and siliceous magmas; hence, Fe/Mg ratios and TiO_2 contents were not buffered during mixing-induced fractionation, and the pre-graben series of rocks is tholeiitic. Conversely, amphibole was a near-liquidus phase during post-graben mixing events, and a calc-alkaline series of rocks resulted. □

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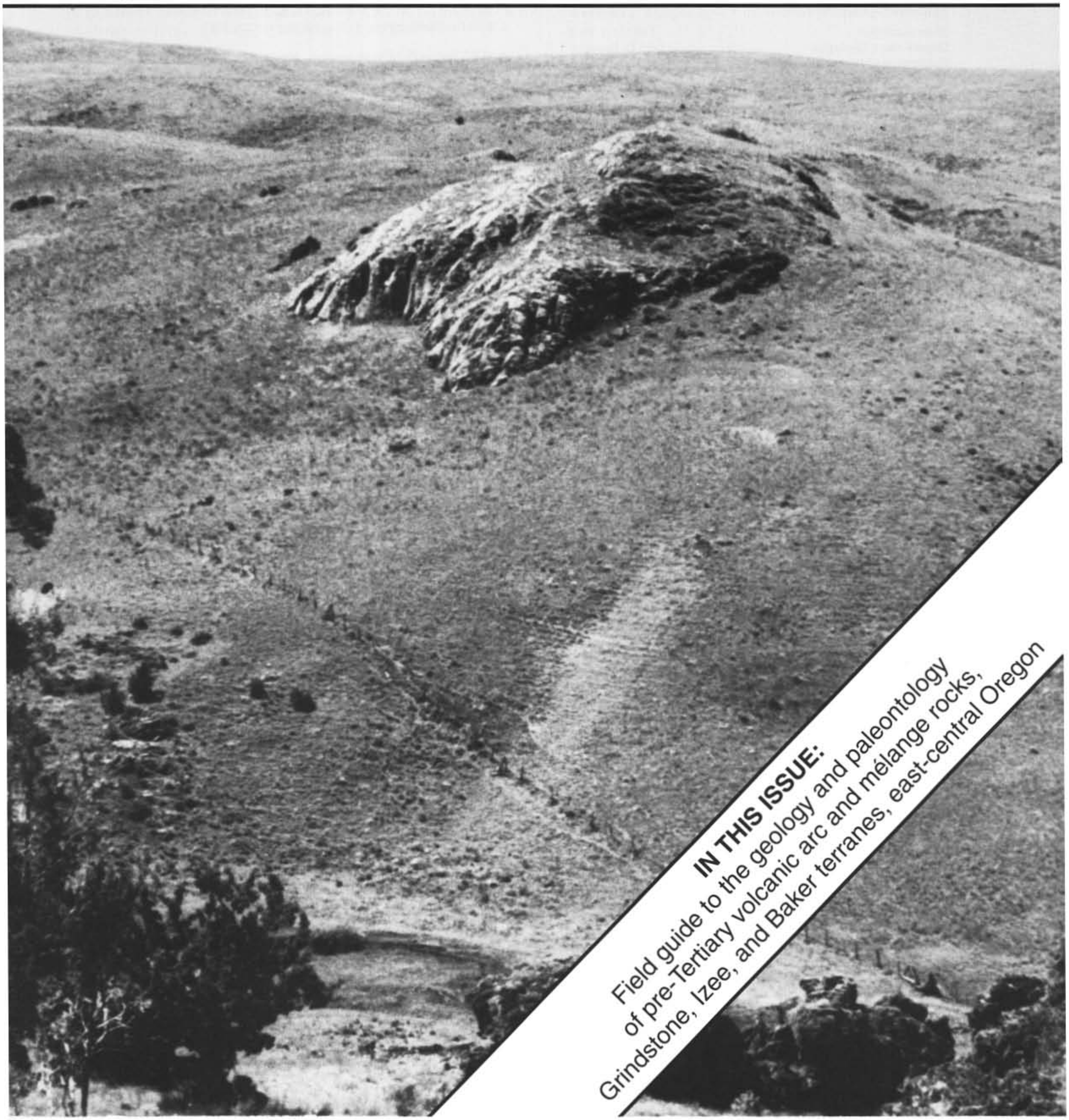

IN THIS ISSUE:
Field guide to the geology and paleontology of pre-Tertiary volcanic arc and mélange rocks, Grindstone, Izee, and Baker terranes, east-central Oregon

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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*, 7th ed., 1991 or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

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

Cover photo

Large exposure of some of the oldest rock found in Oregon: Devonian limestone that was deposited somewhere nearly 400 million years ago and eventually attached to what was then the western edge of the North American continent. The location shown here, along Trout Creek in the Suplee area of east-central Oregon, is one of the stops of the field trip guide beginning on the next page.

OIL AND GAS NEWS

Drilling resumes at Mist Gas Field

During October, Nahama and Weagant Energy Company of Bakersfield, California, resumed a multi-well drilling program at the Mist Gas Field, Columbia County, Oregon. Thus far, three wells have been drilled this year: one is completed and producing gas and two are currently suspended. Drilling operations are underway at the fourth well which is the Wilson 11A-5-65, located in NW¼ sec. 5, T. 6 N., R. 5 W., Columbia County. Taylor Drilling Company, Chehalis, Washington, is the drilling contractor.

NWPA holds field symposium, announces workshop

The Northwest Petroleum Association (NWPA) held its annual field symposium at Lincoln City, Oregon, on October 11-13. The theme for the symposium was "New Exploration Concepts and Opportunities for the Pacific Northwest." Approximately 64 people attended the symposium, which covered topics of geological, geophysical, regulatory, environmental, legal, and land interests. Ray Wells, U.S. Geological Survey (USGS), and Alan Niem, Oregon State University, led an excellent field trip from Lincoln City to Tillamook to see the geology of the Oregon Coast.

For November 13, the NWPA has scheduled a meeting to include a workshop immediately following its monthly luncheon. The workshop will be on the national assessment of undiscovered oil and gas resources on the federal outer continental shelf, in state waters, and onshore. The USGS and the U.S. Marine Minerals Service will present the methodology of the assessment; at the subsequent workshop, individuals will be invited to suggest and describe hydrocarbon plays in the Pacific Northwest for possible formal designation as assessment plays. Contact Dan Wermiel at the Portland office of the Oregon Department of Geology and Mineral Industries for further information. □

Results of Santiam Pass drilling program now on open file

The Oregon Department of Geology and Mineral Industries (DOGAMI) has placed on open file the final report on results of the scientific drilling program conducted at Santiam Pass in the Cascade Range.

Geology and Geothermal Resources of the Santiam Pass Area of the Oregon Cascade Range, Deschutes, Jefferson, and Linn Counties, Oregon, edited by Brittain E. Hill.
DOGAMI Open-File Report O-92-3, 61 p., 1 map. Price $6.

This report describes in four chapters the drilling history of the Santiam Pass 77-24 well, the geologic setting of the Santiam Pass area, stratigraphy and petrology of the drill core, and the thermal results of the drilling. Appendices present descriptions and results of analytic work with surface samples, drill core sections, and thin sections. The blackline diazo map and cross section (scale 1:62,500) show geology, structure, and the locations of mountain peaks, samples used for radiometric dating, and temperature-gradient holes.

The new publication is now available at the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444. Orders may be charged to credit cards by mail, FAX, or phone. FAX number is (503) 731-4066. Orders under $50 require prepayment except for credit-card orders. Purchase by mail and over the counter is also possible at the DOGAMI field offices: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133; and 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496. □

Field guide to the geology and paleontology of pre-Tertiary volcanic arc and mélange rocks, Grindstone, Izee, and Baker terranes, east-central Oregon

by Charles D. Blome, U.S. Geological Survey, MS 919, Federal Center, Denver, CO 80225; and Merlynd K. Nestell, Department of Geology, University of Texas at Arlington, Arlington, TX 76019-0049.

This field guide was prepared for Part 1 of a field trip conducted May 13-16, 1992, in conjunction with the Cordilleran Section meeting of the Geological Society of America and entitled "Pre-Tertiary volcanic arc and mélange rocks of east-central Oregon." The first part of the field trip deals with volcaniclastic and mélange rocks in the Grindstone and Izee terranes and western part of the Baker terrane. Part 2, which deals with the pre-Tertiary sedimentary, plutonic, and ultramafic rocks in the western part of the Baker terrane, was led by Ellen Bishop and Howard Brooks, and the field guide will be published in a future issue of *Oregon Geology*.

Please note that part of the field trip entered private land and that the authors give special instructions at the beginning of the excursion itinerary. Permission to visit private land must be obtained in advance from the land owners listed in the acknowledgments. —*ed.*

INTRODUCTION

Pre-Cenozoic rocks in the Blue Mountains Province occur in a belt that trends northeast from about 15 mi south of the village of Paulina in central Oregon to near Grangeville, Idaho. Numerous inliers or windows of Paleozoic and Mesozoic (Devonian to Cretaceous) rocks in this belt are surrounded by Tertiary lavas and sedimentary rocks of continental origin (Brooks and Vallier, 1978). These inliers contain the only pre-Tertiary outcrops known between southern British Columbia and northern Washington on the north and northwestern Nevada on the south (Dickinson and Thayer, 1978). The Paleozoic inliers of the Grindstone terrane are of particular importance to Pacific Northwest geology because they are relatively unmetamorphosed (at most to zeolite grade).

This province can be described as a collage of tectonic blocks or terranes, some of which have been displaced from their original site of formation (Blome and others, 1986). Although the terrane concept (Irwin, 1972) has helped to interpret the geological relationships among the Blue Mountains structural units, the varied terminology can be confusing. A number of terrane names have been applied to the eastern Oregon units, but we use the terrane nomenclature of Silberling and others (1984, 1987), which includes, from southwest to northeast, the Grindstone, Izee, Baker, Olds Ferry, and Wallowa terranes (Figure 1). This field trip guide is an outgrowth of a study by the authors on the geology and tectonic history of the Grindstone terrane (Blome and Nestell, 1991). A complementary study is being prepared by Nestell and Blome on the paleontology and tectonic history of the Baker terrane.

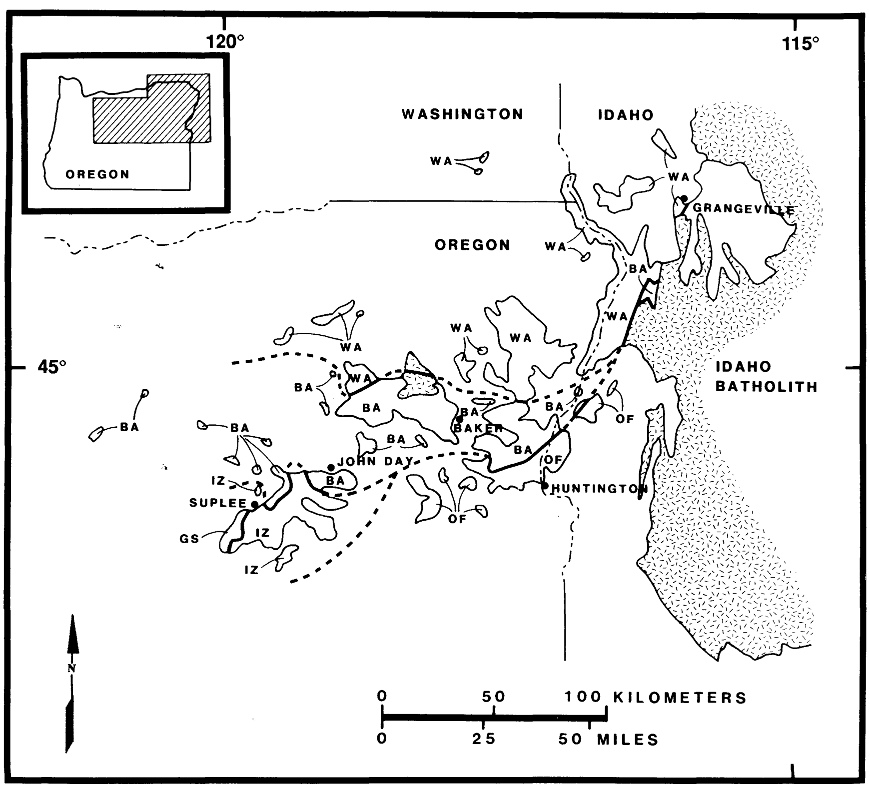

Figure 1. Distribution of pre-Tertiary rocks showing generalized terrane boundaries for the southwestern part of the Blue Mountains Province. GS = Grindstone terrane, IZ = Izee terrane, BA = Baker terrane, OF = Olds Ferry terrane, WA = Wallowa terrane. Terminology after Silberling and others (1984, 1987).

OVERVIEW

Grindstone terrane

The Grindstone terrane was first named the Paleozoic shelf terrane by Vallier and others (1977) because of the presence of shallow-water Devonian rocks. Grindstone terrane rocks were included in the mélange terrane of Dickinson and Thayer (1978), dismembered oceanic terrane by Brooks and Vallier (1978), central mélange terrane by Dickinson (1979), and oceanic/mélange terrane by Mullen and Sarewitz (1983).

The Grindstone terrane, exposed along the southwestern border of the province, contains some of the oldest rock units, including (1) Middle Devonian limestone interstratified with sandstone, chert, and argillite (unit Dl in

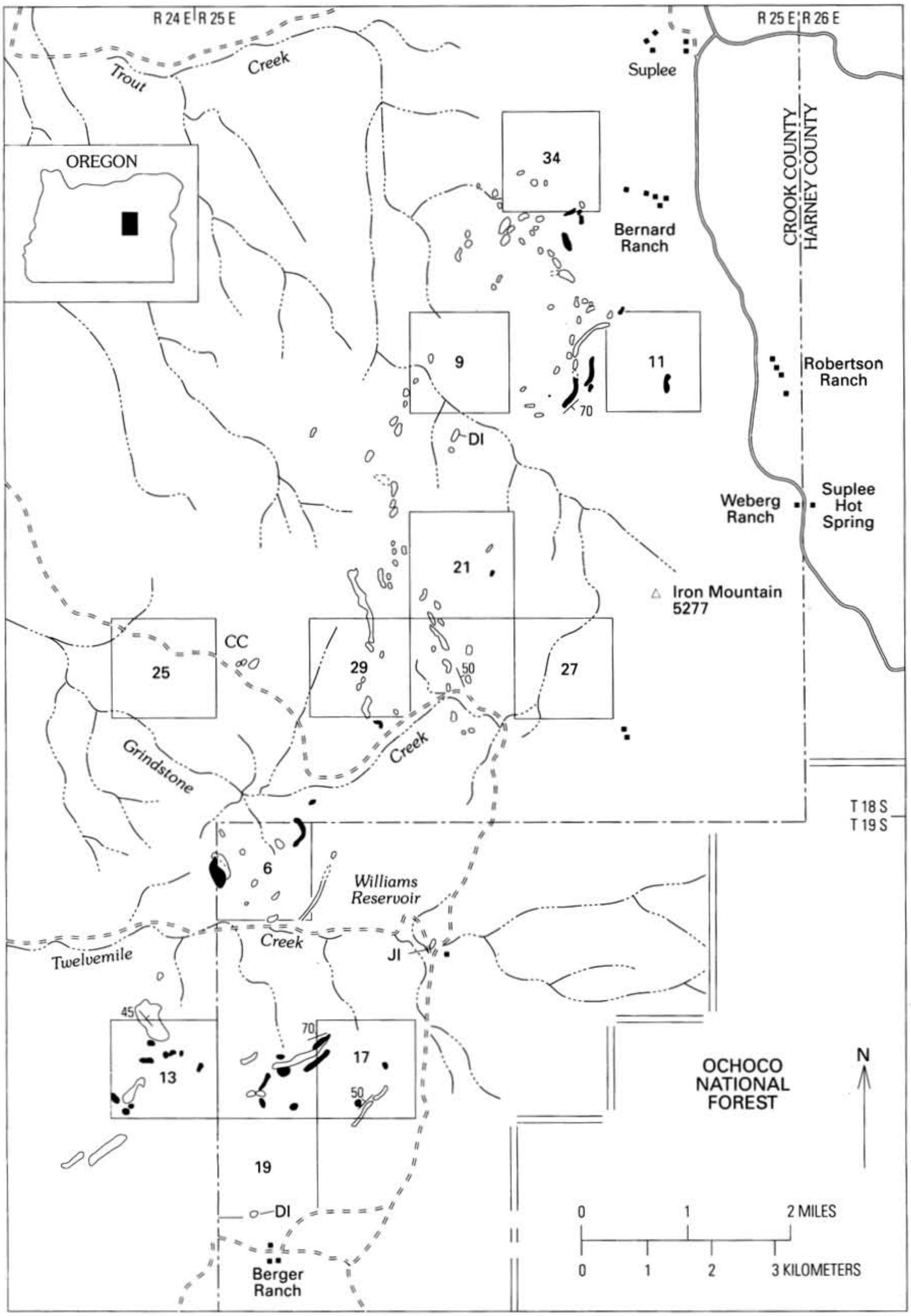

Figure 2. Distribution of Coyote Butte limestone unit (outlined areas) and unnamed chert exposures (darkened areas) (Grindstone terrane; Grindstone-Twelvemile mélange area in Figure 3). Dl = unnamed Middle Devonian limestone, CC = Coffee Creek limestone unit, Jl = unnamed Lower Jurassic limestone. Numbered squares are sections of the township/range surveying system.

Figure 2); (2) Mississippian limestone surrounded by and intermixed with calcareous and conglomeratic sandstone (originally called the Coffee Creek Formation by Merriam and Berthiaume, 1943; unit CC in Figure 2); (3) Pennsylvanian(?) mudstone, sandstone, and conglomerate (originally called the Spotted Ridge Formation by Merriam and Berthiaume, 1943) containing plant remains and minor limestone; (4) Lower Permian, partly fusulinacean-, brachiopod-, and bryozoan-bearing, volcaniclastic and dolomitic limestone (originally called the Coyote Butte Formation by Merriam and Berthiaume, 1943; outlined areas in Figure 2); (5) unnamed Permian and Lower Triassic radiolarian-bearing multicolored chert and dark mudstone (darkened areas in Figure 2); and (6) Permian and Triassic volcaniclastic sandstone and siltstone, limestone breccia, and pebble to boulder conglomerate (Blome and others, 1986; Blome and Nestell, 1991).

Izee terrane

The volcaniclastic-rich Izee terrane of Silberling and others (1984, 1987) includes the western half of the oceanic terrane of Vallier and others (1977), the western half of Dickinson's (1979) Mesozoic clastic terrane, and the western half of the fore-arc basin terrane of Brooks (1979b). The Izee terrane contains a thick, mainly flyschoid sequence of clastic sedimentary rocks, along with subordinate limestone and volcanic and volcaniclastic rocks that range in age from Late Triassic (Carnian) through Middle Jurassic (Callovian). This terrane contains Upper Triassic turbidite sequences with minor fine-grained basinal deposits that lie atop the Grindstone terrane. Rocks immediately adjacent to the Grindstone terrane in the Izee terrane consist of the chert-rich conglomerate assigned to the Begg Member of the Vester Formation, minor unnamed Lower Jurassic limestone and siltstone, and Middle Jurassic mudstone, siltstone, and sandstone that belong to the Weberg, Warm Springs, and Basey Members of the Snowshoe Formation (Dickinson and Vigrass, 1965; Blome and Nestell, 1991).

The northward-trending Poison Creek Fault divides the Upper Triassic and Lower Jurassic sedimentary rocks into two distinct stratigraphic units (Figure 3). Upper Triassic and Lower Jurassic rocks west of the fault are represented by the Vester Formation (Begg, Brisbois, and Rail Cabin Mudstone Members) and the Graylock Formation. The Rail Cabin was originally named the Rail Cabin Argillite by Dickinson and Vigrass (1965), later renamed the Rail Cabin Mudstone by Blome (1984), and most recently was reduced in rank as the Rail Cabin Member of the Vester Formation (Blome and others, 1986). Triassic and Lower Jurassic rocks east of the Poison Creek Fault include the Upper Triassic Fields Creek Formation and Laycock Graywacke and the Lower Jurassic Murderers Creek Graywacke and Keller Creek Shale. The varied biostratigraphic ages of these units are discussed by Blome and others (1986). The Triassic and Lower Jurassic units are overlain unconformably by Jurassic volcaniclastic fore-arc basin rocks of the Mowich Group and Snowshoe, Trowbridge, and Lonesome Formations (Dickinson and Vigrass, 1965; Dickinson and Thayer, 1978). Dickinson (1979) interpreted the volcaniclastic rock assemblages as mainly turbidites but stated that some shelf deposits are related to transgressive unconformities.

Baker terrane

Rock units now included in the Baker terrane of Silberling and others (1984, 1987) were originally defined as the oceanic terrane by Vallier and others (1977) because they represent structurally dismembered blocks of oceanic origin. They were also termed the dismembered oceanic terrane by Brooks and Vallier (1978) and central mélange terrane by Dickinson and Thayer (1978). Dickinson and Thayer (1978) and Dickinson (1979) considered the Miller Mountain, Frenchy Butte, and Grindstone-Twelvemile mélange areas (Figure 3) to be parts of their central mélange terrane. Silberling and others (1984, 1987) later integrated the Miller Mountain and Frenchy Butte areas into the Baker terrane.

The Baker terrane contains disrupted late Paleozoic oceanic crustal blocks, associated deep-marine sedimentary rocks of late Paleozoic and Triassic age, and tectonically mixed blocks of various rock types. Extensive zones of mélange occur in the southwestern part of the terrane, whereas more coherent rock packages exist in the

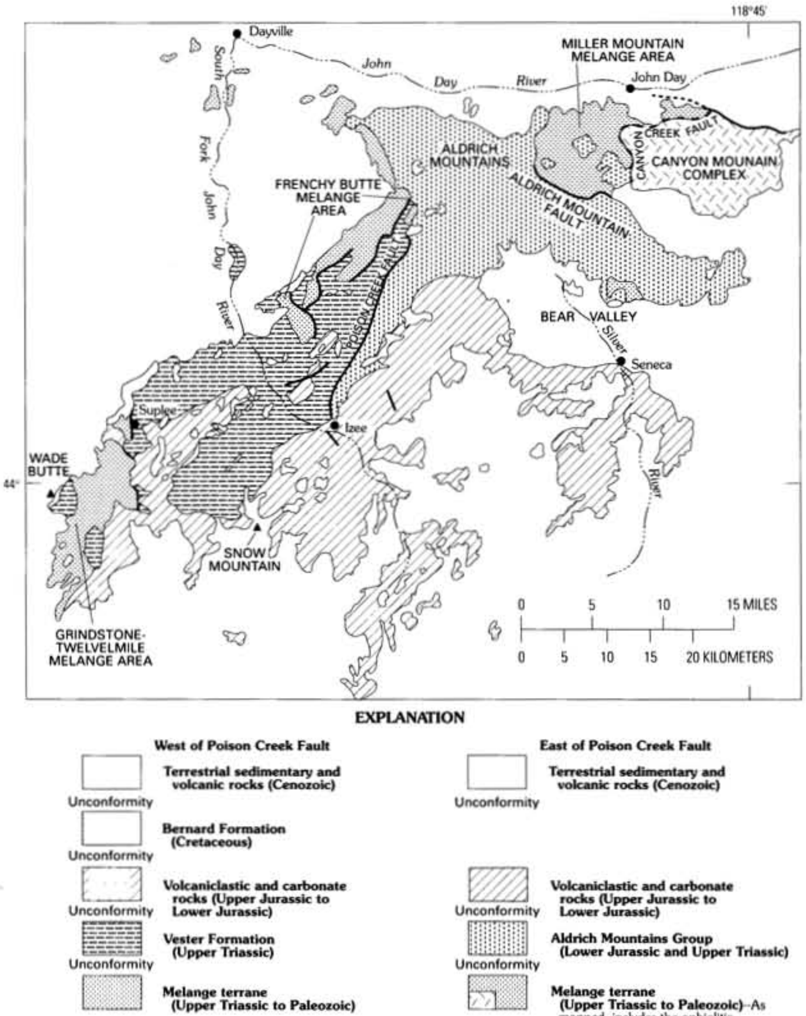

Figure 3. Generalized geologic map of the Izee and Grindstone terranes showing the location of mélange areas (modified from Dickinson and Thayer, 1978). Frenchy Butte and Miller Mountain mélange areas are now included within the Baker terrane, Grindstone-Twelvemile mélange area is considered the Grindstone terrane, and other rocks between Suplee and John Day are placed within the Izee terrane (Silberling and others, 1984, 1987).

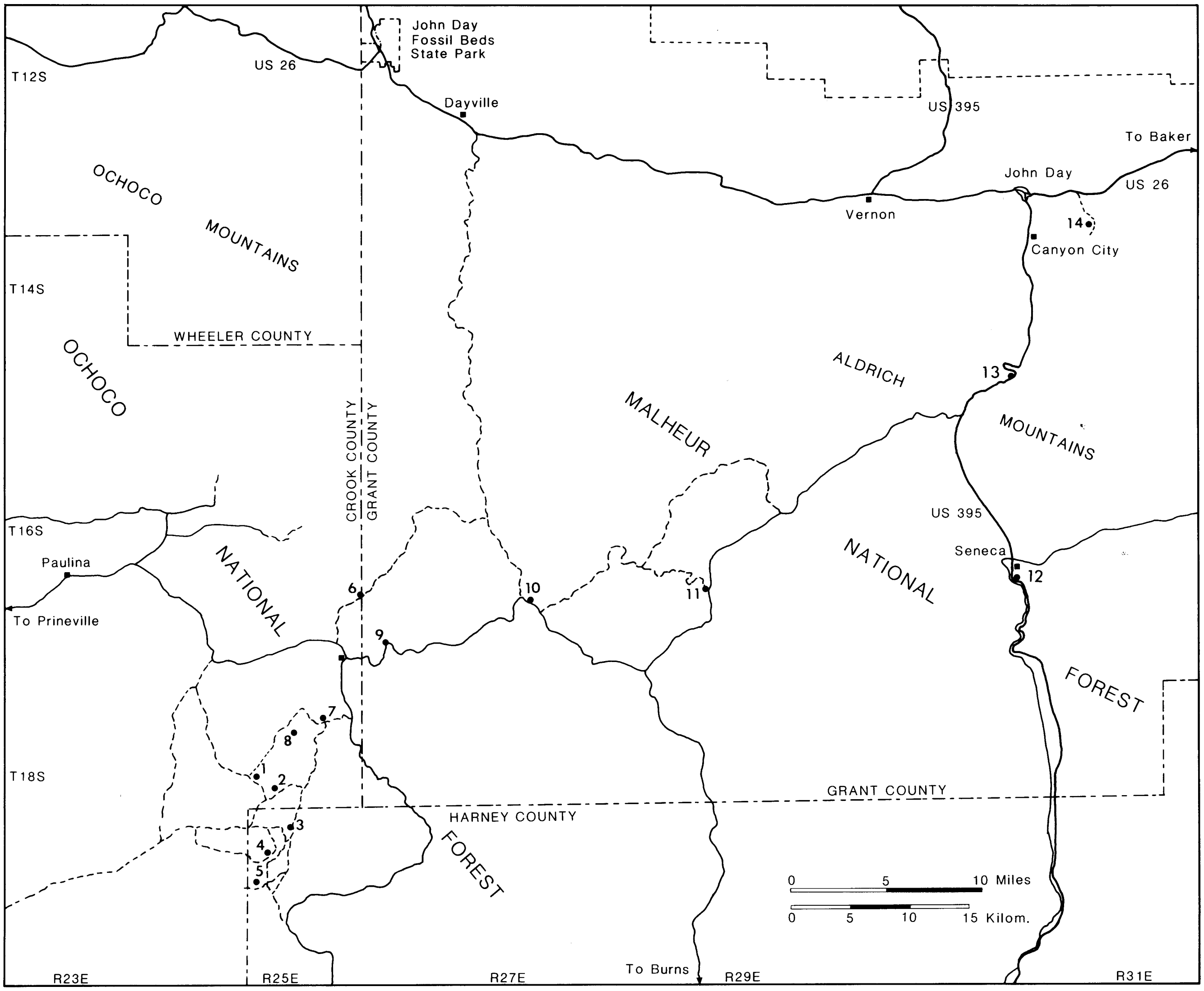

Figure 4. Map showing field trip stops for pre-Tertiary volcanic arc and mélange rocks of the Grindstone and Izee terranes and western part of the Baker terrane, east-central Oregon.

northwestern and eastern parts. Large bodies of highly deformed but lithologically coherent metamorphic and sedimentary rocks, such as the Burnt River Schist and the informally named Nelson Marble of Prostka (1967), are also present in the eastern part (Vallier and others, 1977; Silberling and others, 1984, 1987).

Blocks of serpentinite and greenstone, siliceous shale, chert, and associated metamorphosed (greenschist-grade) volcaniclastic rocks compose the Miller Mountain mélange (Figure 3). This mélange is separated from the Canyon Mountain Complex (Brown and Thayer, 1966) by the Canyon Creek Fault on the east and from the Aldrich Mountains Group of the Izee terrane by the Aldrich Mountain Fault (Figure 3). The Canyon Mountain Complex, well exposed southeast of the town of John Day (Brown and Thayer, 1966; Avé Lallemant, 1976), represents the basement rocks for the mélange (Vallier and others, 1977). Mid-Permian Tethyan fusulinaceans (verbeekinids and neoschwagerinids), and Middle (late Ladinian) to Late Triassic (early Carnian) radiolarians have been reported from limestone and chert pods, respectively, southeast of John Day on Little Dog Creek (Dickinson and Thayer, 1978; Nestell and MacLeod, 1984; Blome and others, 1986). Excellent exposures of serpentinite and pyroxenite are present a few hundred meters east of the limestone and chert outcrops.

The Frenchy Butte mélange area, located north of the town of Izee between exposures of the Fields Creek Formation (of the Aldrich Mountains Group) and the South Fork of the John Day River (Figure 3), is composed almost entirely of serpentinite and metavolcanic rocks. Although not fossiliferous, this mélange area was presumed by Dickinson and Thayer (1978) to be either Permian or Triassic in age.

Upper Paleozoic and lower Mesozoic rocks in the eastern part of the Baker terrane near Baker City, Oregon, include abundant chert, argillite, siliceous tuff, and rare coarse-grained sedimentary rocks (Vallier and others, 1977; Brooks and Vallier, 1978). Incorporated in this part of the terrane are argillite, chert, tuff, and limestone of the Elkhorn Ridge Argillite; thin-layered phyllitic quartzite, greenstone, and marble of the Burnt River Schist (Gilluly, 1937); and basalt flows and varied volcaniclastic rocks. Most of the rocks have undergone severe structural deformation and metamorphism (greenschist to rarely amphibolite facies) and in many areas are structurally intermixed with plutonic bodies.

The Baker terrane (Figure 1) is bounded on the north by Wallowa terrane Lower Permian to Middle and Upper Triassic metavolcanic and volcaniclastic rocks overlain by Upper Triassic and Lower

Jurassic carbonate rocks and clastic sequences (Silberling and others, 1984, 1987). Directly south of the Baker terrane are Upper Triassic mafic and intermediate volcanic and volcaniclastic rocks of the Huntington Formation of Brooks (1979a) in the Olds Ferry terrane (Figure 1). These are overlain by Lower Jurassic (and possibly uppermost Triassic) limestone and coarse-grained volcaniclastic rocks and Lower and Middle Jurassic sedimentary rocks of the Weatherby Formation of Brooks (1979a).

Only one locality in the generally unfossiliferous western part of the Baker terrane will be discussed in this field trip guide. Chert and limestone similar to that found in the type area of the Elkhorn Ridge Argillite in the eastern part of the Baker terrane can be found north of the Aldrich Mountains, southeast of John Day along Little Dog Creek. Here, limestone containing mid-Permian Tethyan fusulinaceans is juxtaposed with chert containing Middle and Late Triassic radiolarians (Nestell and MacLeod, 1984; Blome and others, 1986). Mélange, ophiolitic, and plutonic rocks in other parts of the Baker terrane will be discussed in connection with Part 2 of this field trip.

EXCURSION ITINERARY

Before you start

All roads and stops for this field trip guide are illustrated in Figure 4. **Stops 1-5 and 7-8 are behind locked gates on private ranches, and written permission to visit them must be obtained in advance from the property owners (see Acknowledgments).** These off-road stops are included in this guide because of their geologic uniqueness and importance to the geology and tectonics of central Oregon.

A good overview of the area can be obtained by visiting the stops that are on public land or near all-weather roads. The field trip could then begin with Stop 6 and continue with Stops 9-14. Stop 6 is on National Forest Service land but inaccessible in wet weather. At Stop 14, permission to venture off the Dog Creek road must be obtained.

The area through which this field trip passes is in a remote part of Oregon, and obvious precautions for travel should be observed. For example, gasoline and supplies in the Grindstone terrane are available only at the general store in the village of Paulina. The closest facilities in the Izee terrane and western part of the Baker terrane are in the John Day area. Reasonable caution should be taken in following the road log, as many of the unpaved roads on private ranches are impassable in wet weather (even with four-wheel drive). Stopping along roads should be done with due caution.

En route

The excursion begins in Prineville, Oregon. Travel approximately 64 mi from Prineville, Oregon, to Paulina via State Highway 380. Field trip mileage starts at the east edge of Paulina. Travel east on paved road from Paulina (Crook County Road 112) approximately 3.6 mi to Y-intersection, take the east fork and travel another 6.6 mi to turnoff (right) onto Grindstone Creek-Twelvemile Creek dirt road traveling south. Travel south-southwest past cattle pens (0.7 mi) toward basalt plateau (Grindstone Rim). Continue on dirt road approximately 1.5 mi to Y-intersection, take the left fork and head south-southeast on dirt road another 2.5 mi to the locked gate of the G.I. Ranch. **Written permission must be obtained for travel beyond this point for Stops 1-5 and 7-8** (Stop 6 is on National Forest Service land). Continue east 3.0 mi and park for Stop 1: Coffee Creek limestone unit (SE¼NW¼ sec. 30, T. 18 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle; limestone pods with nearly vertical bedding located a short 0.1-mi hike east of dirt road).

STOP 1—COFFEE CREEK LIMESTONE UNIT, CENTRAL GRINDSTONE TERRANE

Limestone exposed on Coffee Creek, a drainage that enters Grindstone Creek south of Wade Butte, was named the Coffee Creek Formation by Merriam and Berthiaume (1943). The limestone exposures at this stop in the west-central part of the terrane (CC in Figure 2) represent their type section (Figure 5). According to Merriam and Berthiaume, typical Coffee Creek rock types include well-bedded carbonaceous limestone, muddy to sandy limestone, and calcareous sandstone; calcareous sandstone accounts for a large part of the exposures. The lower part of their section consists of sandy limestone and sandstone and grades up into argillaceous limestone.

Buddenhagen (1967) stated that he had difficulty establishing the lower and upper limits of the Coffee Creek Formation and estimating formational thickness. With the exception of the exposure in sec. 30 (CC in Figure 2), Coffee Creek exposures are small (less than 20 ft [6 m] thick) and generally restricted to the west-central part of the Grindstone terrane. The lack of mappability and traceability of the Coffee Creek exposures prompted Blome and Nestell (1991) to recommend that formal formational status be discontinued for these rocks and that the informal name "Coffee Creek limestone unit" be retained.

Merriam and Berthiaume (1943) listed corals, brachiopods, small loxonemoid gastropods, and lithistid sponge spicules from this exposure. They also stated that, because the brachiopod *Striatifera* is present, the Coffee Creek sandstones are no older than Early Carboniferous. Also present is the brachiopod *Gigantella*, whose horizon is roughly Mississippian (Visean) in age. The Coffee Creek was assigned a Late Mississippian (middle and late Meramecian and Chesterian) age by Poole and Sandberg (1977). Skinner and Wilde (1965) suggested that the Coffee Creek contained fusulinacean faunas of Early Pennsylvanian age, but fusulinaceans (*Eostaffella*) and corals (*Hexaphyllia*) collected near this locality are indicative of a Late Mississippian (Chesterian) age (Sada and Danner, 1973).

En route

Continue approximately 3.0 mi south and southeast along the same dirt road and park for Stop 2: Coyote Butte limestone unit (NW¼NW¼ sec. 33, T. 18 S., R. 25 E., Delintment Lake 7.5′ quadrangle; three large limestone blocks located on flank of ridge 0.25 mi southeast of dirt road).

STOP 2—COYOTE BUTTE LIMESTONE UNIT, CENTRAL GRINDSTONE TERRANE

The Coyote Butte limestone unit is lithologically consistent throughout much of the terrane in being coarser and crinoid- and fusulinacean-bearing in the lower parts of its exposures and finer grained and brachiopod-bearing in its upper parts. The limestone exposures strike northeast in the northern part of the terrane; the strike changes to northwest in the central part and reverts to northeast in the southern part (Figure 2). Individual beds within each exposure can dip steeply (to 75°). Some limestone blocks possess relatively uniform stratigraphy, whereas others are overturned, and some exhibit disturbed and deformed bedding. Blome and Nestell (1991) recommended that formal formational status of the Coyote Butte Formation (Merriam and Berthiaume, 1943) be discontinued because of the lack of mappability between limestone blocks and their chaotic intermixing with surrounding chert and volcaniclastic rocks; they also recommended that the informal name "Coyote Butte limestone unit" be retained.

At this locality in the central part of the terrane just north of Grindstone Creek (Figure 6), dolomitic and crinoidal limestone blocks containing limestone breccia and replacement chert crop out over several kilometers in a north-northeast trend (Figure 2). One of the limestone pods north of the road has yielded poorly preserved Early Permian conodonts (*Sweetognathus*), silicified gastropods (*Tapinotomaria*?), and poorly preserved dolomitized fusulinaceans (probably *Schwagerina*). At some localities, volcaniclastic rocks (andesitic, dacitic, and welded-tuff rock fragments) are also found in Coyote Butte fusulinacean- and bryozoan-bearing limestone, and zeolites replacing parts of fossil fragments (e.g., crinoid columnals) are common.

En route

Continue approximately 0.7 mi south and east to road cuts just west of small unnamed lake. Unnamed chert and conglomerate (questionably assigned to the Begg Member of the Vester Formation) can be observed at these road cuts. Continue 0.2 mi and turn south across earth dam and go another 3.6 mi to old Sherman ranch house. En route across the topographic high, one can see to the south the limestone exposures at Three Buttes (i.e., Coyote Butte; Figure 7). Travel approximately another 0.2 mi west and park for Stop 3: Unnamed Lower Jurassic limestone and siltstone (NE¼NE¼ sec. 8, T. 19 S., R. 25 E., Delintment Lake 7.5′ quadrangle; exposure just north of dirt road).

STOP 3—UNNAMED LOWER JURASSIC LIMESTONE AND SILTSTONE, CENTRAL GRINDSTONE TERRANE

A small exposure of limestone, shale, and siltstone (unit Jl in Figure 2; Figure 8) crops out north of Twelvemile Creek along the Grindstone-Izee terrane boundary. Buddenhagen (1967) reported that ammonites from this exposure are indicative of an Early Jurassic (Hettangian) age. Coeval siltstone-limestone exposures, assigned by Dickinson and Vigrass (1965, p. 29) to the Graylock Formation, crop out near Morgan Mountain in the adjacent Izee terrane to the northeast.

En route

From Stop 3, travel 0.6 mi south across dam to intersection. To continue field trip, take left fork heading south (right fork continues west along Twelvemile Creek and ultimately back to Paulina) and proceed another 0.6 mi to Y-intersection. Take the left fork (right fork goes to Delore Ranch) and travel 1.2 mi to T-intersection, turn right (north-northwest) and go 0.85 mi to U-shaped loop road and park for Stop 4: Coyote Butte limestone unit at Three Buttes (called Coyote Butte by Merriam and Berthiaume, 1943; S½NE¼ sec. 18, also W½NW¼ sec. 17, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle. The interconnected, southwest-northeast-trending Coyote Butte limestone blocks and adjacent chert are approximately a quarter-mile hike due north.

STOP 4—COYOTE BUTTE LIMESTONE UNIT AND UNNAMED CHERT, COYOTE BUTTE (THREE BUTTES), SOUTHERN GRINDSTONE TERRANE

Coyote Butte limestone unit

The Coyote Butte Formation was named by Merriam and Berthiaume (1943) for the long, prominent limestone ridge that constitutes most of Three Buttes in the southern part of the Grindstone terrane (sec. 18 in Figure 2; Figure 7). The limestone at Coyote Butte can be roughly divided into a basal light-gray, massive crinoidal, fusulinacean- and bryozoan-bearing packstone, overlain by a light-gray, medium- to thick-bedded, finer grained packstone and grainstone (Figure 9a), and an upper darker gray to yellow-brown, brachiopod-bearing argillaceous wackestone (Wardlaw and others, 1982, p. 13). According to Merriam and Berthiaume (1943), the Coyote Butte is approximately 900 ft (274 m) thick, but an exact thickness could not be determined because of poor bedding and folding.

Other significant Permian limestone exposures occur west and southwest of Coyote Butte. For example, three northerly trending limestone blocks exposed west of Three Buttes (the northeast-trending block in the southwest quarter of sec. 13, sometimes called Tucker's Butte; Figures 2 and 9b) are lithologically similar to those found at Three Buttes. Over 200 ft (60 m) of chert-grain and fine-pebble conglomerate interbedded with Coyote Butte limestone is exposed just north of Tucker's Butte on Triangulation Hill (large limestone block on the boundary of secs. 12 and 13; Figure 2). Chert commonly replaces limestone in the southwestern part of the terrane and occurs in the form of unfossiliferous, gray to black, translucent, irregular patches or pinch and swell beds.

Brachiopod, conodont, coral, and fusulinacean faunas from the Coyote Butte limestone unit are indicative of an Early Permian (late Wolfcampian to Leonardian) age (Merriam and Berthiaume, 1943; Wardlaw and others, 1982; Blome and Nestell, 1991). Merriam and Berthiaume (1943) reported earliest Permian fusulinaceans from the stratigraphically lower parts of the Coyote Butte. However, limestones collected from more than 40 localities contain similar fusulinacean faunas of late Wolfcampian to early Leonardian age (Plate 1; Blome and Nestell, 1991). The Coyote Butte fusulinacean faunas have affinities with those described from the middle part of the McCloud Limestone (Zones G and H) in the Shasta Lake area, northern California, and with those described from near Quinn River Crossing in northern Nevada (Skinner and Wilde, 1965, 1966).

Colonial corals from the Coyote Butte limestone include several species of *Heritschioides*, *Petalaxis occidentalis*, and *Thysanophyllum*? sp. (Merriam, 1942; Stevens and Rycerski, 1983). Brachiopod faunas described by Cooper (1957) from stratigraphically higher parts of the Coyote Butte are no older than latest Leonardian and may be as young as early Guadalupian. However, Waterhouse (1976) considered this fauna to be partly late Asselian in age.

Several limestone exposures (Three Buttes, Tucker's Butte, and Triangulation Hill) were sampled for conodonts and fusulinaceans by Wardlaw and others (1982). Their fusulinacean data suggest, at least in part, a Leonardian age, and the sparse conodont faunas are indicative of a Leonardian (= Artinskian; see Furnish, 1973) age for the exposures.

Unnamed chert

Siliceous rocks in the Grindstone terrane include abundant black, green, and red radiolarian chert, siliceous mudstone, and fine-grained tuff. Even though the chert exposures exhibit some lateral coherence, these rocks as a whole were never assigned a formational name and were considered part of the Carboniferous Spotted Ridge Formation according to Merriam and Berthiaume (1943). Ketner (1967) indicated that the upper part of the Coyote Butte Formation was overlain by as much as 900 ft (274 m) of chert.

Facing page, first left, then right column from the top down:

Figure 5. Coffee Creek limestone unit exposure at Stop 1 in west-central part of the Grindstone terrane (CC in Figure 2). Type section of Coffee Creek Formation of Merriam and Berthiaume (1943).

Figure 6. Typical exposures of the fusulinacean-bearing and dolomitic Coyote Butte limestone unit and unnamed chert (upper right) at Stop 2, south side of Grindstone Creek, central part of Grindstone terrane.

Figure 7. View to the south from Williams Reservoir in central part of Grindstone terrane. The three rolling hills (left of center; Three Buttes, also called Coyote Butte) are Coyote Butte limestone unit exposures seen at Stop 4. Type area of Coyote Butte Formation of Merriam and Berthiaume (1943).

Figure 8. Exposure of unnamed Lower Jurassic limestone and siltstone at Stop 3 just west of old Sherman ranch house. Scarce ammonites occur in the shales to the right of the steeply dipping limestones.

Figure 9a. Thin section of massive carbonate grainstone-packstone exposed at the northeast end of Three Buttes (Stop 4). Dark areas are cross sections of fusulinaceans, and light-colored oval areas are crinoid columnals. Field of view 8cm x 4.5cm.

Figure 9b. Exposure of steeply dipping Coyote Butte limestone unit on prominent butte to the west of Three Buttes (sometimes called Tucker's Butte; NW¼SW¼ sec. 13, T. 19 S., R. 24 E., Twelvemile Reservoir 7.5′ quadrangle). Photo taken looking south.

Figure 9c. Exposure of unnamed chert (Stop 4) located just 0.2 mi northeast of Three Buttes (loc. 5 of Blome and Reed, 1992).

Figure 10. Small pod (left side of photo) of Middle Devonian coral-bearing limestone at Stop 5; also informally referred to as the Berger Ranch limestone (Danner, 1977). Limestone pod on right side of photograph is barren of corals and conodonts and is now considered Triassic or Jurassic in age (Blome and Nestell, 1991).


Figure 5.

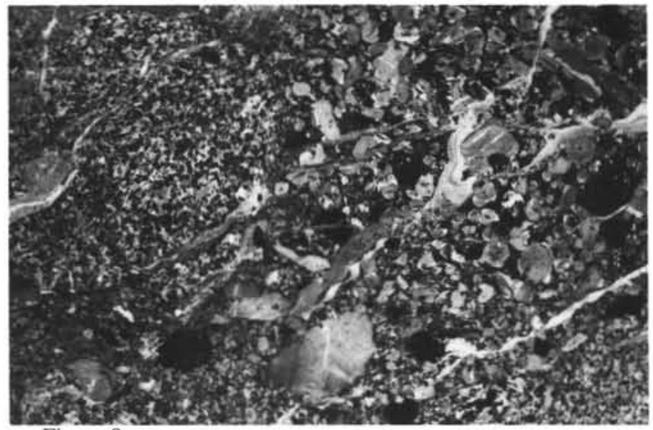
Figure 9a.


Figure 6.

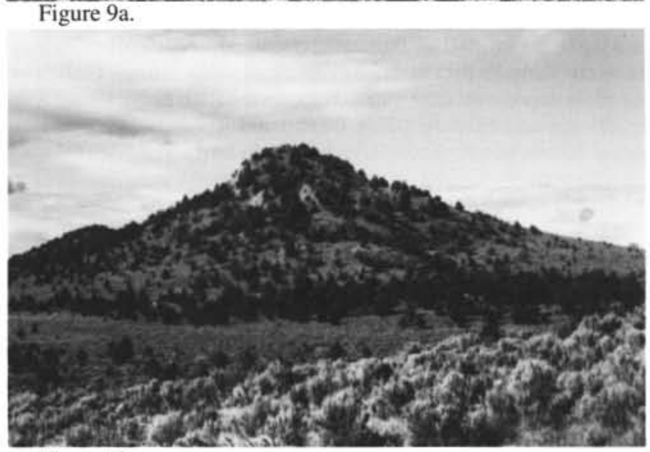
Figure 9b.

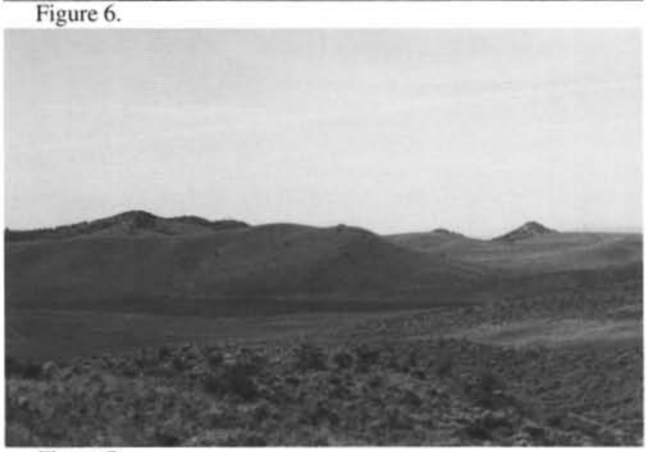
Figure 7.


Figure 9c.


Figure 8.

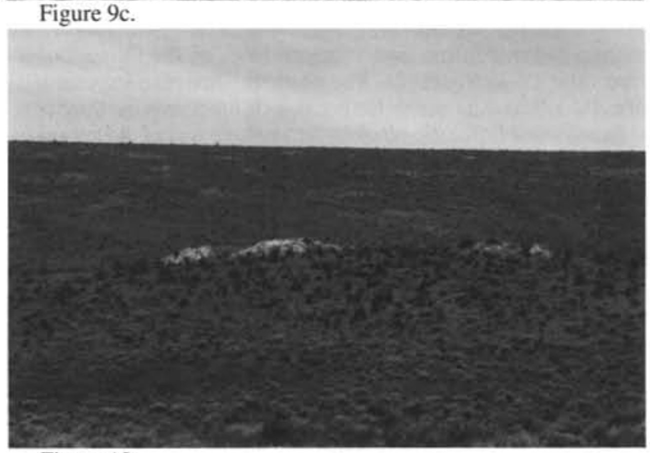
Figure 10.

Abundant chert float and small pods of chert and siliceous mudstone surround Three Buttes (i.e., Coyote Butte) but do not appear to be in depositional contact with the limestone. A red chert exposure approximately 0.2 mi northeast of the eastern extension of Coyote Butte (Figure 9c; NW¼NW¼ sec. 17, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle) contains radiolarian faunas assignable to the mid-Permian (upper Leonardian to lower Guadalupian) *Pseudoalbaillella globosa* Zone of Ishiga (1986; cf. Blome and Nestell, 1991; Blome and Reed, 1992). The common radiolarian taxa (Plate 2) include *Albaillella asymmetrica* Ishiga and Imoto, *Pseudotormentus kamigoriensis* De Wever and Caridroit, *Pseudoalbaillella* sp. aff. *P. globosa* Ishiga and Imoto, *Latentifistula* sp. aff. *L. crux* Nazarov and Ormiston, *Kashiwara magna* Sashida and Tonishi, and *Hegleria mammilla* (Sheng and Wang).

Blome and others (1986) demonstrated that cherts in the Grindstone terrane contain Permian (late Wolfcampian to late Guadalupian) radiolarian faunas. Additional chert collections from more than 40 localities suggest nearly continuous Grindstone chert deposition from Early Permian through Early Triassic time (Blome and Nestell, 1991; Blome and Reed, 1992). Other reported fossils besides radiolarians include Early Triassic conodonts (*Neospathodus pakistanensis* and *Ellisonia* sp.; Wardlaw and Jones, 1980).

Thinly bedded, unfossiliferous, dark-red siliceous mudstone crops out approximately 0.4 mi south of Coyote Butte (boundary between SW¼ and SE¼ sec. 18, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle, just north of road). It is well laminated and iron stained and lacks many of the small-scale sedimentary features (vertical and lateral graded-bedding, cross-bedding, and cut- and fill-structures) common in the dark-colored cherts.

Most of the Grindstone cherts exhibit well-developed bedding that contrasts with many of the metacherts in the adjacent Baker terrane (Figure 1). Multicolored, bedded chert has not been found in the Izee terrane (Blome, 1984; Blome and others, 1986).

En route

Backtrack to last T-intersection, turn due south, and go approximately 1.0 mi to a Y-intersection, take right (southwest) fork, go 0.5 mi to Berger Ranch buildings, and park for Stop 5. Walk approximately 0.4 mi north to fence line. The larger limestone pod immediately north of the fence represents Stop 5: Unnamed Devonian limestone (SE¼SW¼ sec. 19, T. 19 S., R. 25 E., Twelvemile Reservoir 7.5′ quadrangle).

STOP 5—UNNAMED DEVONIAN LIMESTONE NEAR THE OLD BERGER RANCH, SOUTHERN GRINDSTONE TERRANE

Among the oldest Paleozoic rocks in Oregon are two blocks of limestone in the northern and southern parts of the Grindstone terrane (unit Dl in Figure 2). The southern Devonian exposure, informally referred to as the Berger Ranch limestone by Danner (1977), is a small limestone block in the southern part of the terrane just northwest of the Berger Ranch house near the Crook and Harney Counties boundary (Figure 10, southern Dl in Figure 2).

This southernmost limestone block has yielded Middle Devonian (probably Givetian) corals, including *Heliolites* cf. *H. relectus*, *Thamnopora* sp., and *Grypophyllum* sp. (William Oliver, written communication, 1987). A smaller limestone pod that crops out just east of the southern Devonian exposure (Danner, 1977) was assigned a Triassic age by Johnson and Klapper (1978). The only other Devonian fossils known from eastern Oregon are Middle to Late Devonian conodonts (*Polygnathus* spp.) from a limestone exposure in the Baker terrane (Figure 1) to the northeast (Mullen-Morris and Wardlaw, 1986).

En route

Backtrack to the Paulina-Izee paved highway, where the Grindstone Creek-Twelvemile Creek dirt road began (Figure 4). Travel east toward Izee for 7.0 mi, turn north on the dirt road, and go 1.8 mi to the Andy Bernard Ranch. Go past ranch buildings through gate (Note: Although this is a public access road, do not attempt to travel beyond gate in wet weather!) and continue east 2.0 mi to Crook-Grant Counties boundary and park for Stop 6: Coyote Butte limestone unit, northern Grindstone terrane (near intersection of secs. 1/12 and 6/7, T. 17 S., Rs. 25 and 26 E., respectively, Suplee 7.5′ quadrangle, Figure 11a; one large and two small knobs of the Coyote Butte limestone unit located 1.6 mi northeast of ranch house; another limestone knob located 0.5 mi to the northeast, all exposed on north side of road).

STOP 6—COYOTE BUTTE LIMESTONE UNIT NEAR BERNARD RANCH, NORTHERN EDGE OF GRINDSTONE TERRANE

One large and two small fossiliferous limestone blocks crop out near the boundary between Crook and Grant Counties (Figure 11a). This locality is also equivalent to locality OR-4 of Skinner and Wilde (1966) and locality V192 of Dickinson and Vigrass (1965).

The northeasternmost limestone pod (Figures 11a and 11b; NE¼SW¼ sec. 6, T. 17 S., R. 26 E., Suplee 7.5′ quadrangle) is equivalent to locality OR-5 of Skinner and Wilde (1966) and locality V193 of Dickinson and Vigrass (1965). This exposure represents one of the few places where large blocks of Coyote Butte limestone are exposed on public property. Abundant volcaniclastic debris composed of andesitic, dacitic, and welded-tuff rock fragments and zeolites replacing parts of the fossil debris (Figure 11c) have been reported from one of the small limestone blocks (Blome and Nestell, 1991). Skinner and Wilde (1966) described Early Permian (late Wolfcampian or early Leonardian) fusulinaceans (Plate 1) from these limestone blocks.

En route

Travel west and south back to Paulina-Izee paved road, turn east, go 1.0 mi, and turn south onto paved road (Crook County Road 318) toward Robertson and Weberg Ranches. Travel south and go 3.4 mi to four-way intersection at Robertson Ranch, then turn west onto dirt road and go 1.7 mi to Y-intersection, take the left fork and proceed

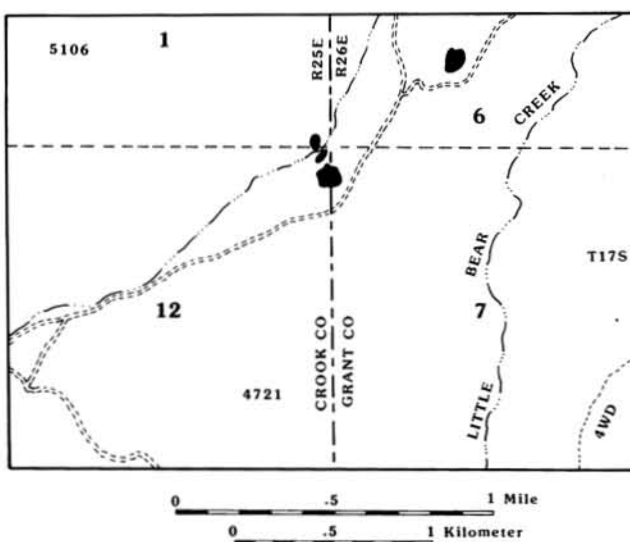

Figure 11a. Distribution of Coyote Butte limestone blocks at Stop 6 along the northern boundary of the Grindstone terrane, near boundary between Crook and Harney Counties. Large numbers identify sections of the township/range surveying system.

Figure 11b. Large pod of the Coyote Butte limestone unit at Stop 6 on forest service road northeast of the Bernard ranch.

Figure 11c. Thin section of carbonate (grainstone) from small limestone pod at Stop 6, north side of small drainage (NE corner sec. 12, T. 17 S., R. 25 E., Suplee 7.5′ quadrangle; loc. 35S-17B of Blome and Nestell, 1991). Crinoid columnal coated with bryozoan in center of photo. Field of view 2.5cm x 1.7cm.

0.5 mi to another Y-intersection, proceed on right fork (new road!) 0.3 mi, and park for Stop 7: Unnamed chert unit (SE¼NE¼ sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle). Hike approximately a quarter of a mile north to top of north-south trending ridge on east side of fence line to view unnamed red chert exposures. Conglomerate and volcaniclastic sandstone can be seen a short hike (0.4 mi) to the west along the dirt road (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle).

STOP 7—UNNAMED CHERT AND BEGG MEMBER OF VESTER FORMATION, NORTHERN GRINDSTONE TERRANE

Unnamed chert

Chert is sparsely exposed in the northern part of the terrane as lenticular blocks, many of which are elongate and aligned in a general northeast-southwest-trending direction and parallel the Coyote Butte exposures (Figure 2). The chert exposures are typically nonresistant (low lying), red and black, and thickly bedded in the north near the North Fork of Trout Creek. Thin intrabeds of dark, red to black mudstone and shale represent a minor fraction of the siliceous rocks. The northern bedded chert exposures were informally referred to as the Birdsong beds by Buddenhagen (1967).

Narrow exposures of red chert are an easy hike north from an unmapped dirt road that leads west from the four-way intersection of the paved road to Suplee and the road to the Robertson Ranch (Figure 4). One exposure of red chert can be seen approximately a quarter of a mile north of the dirt road (Figures 12a and 12b). The radiolarian faunas extracted from this exposure (Plate 2) are the oldest in the Grindstone terrane (loc. 2 of Blome and Reed, 1992) and correlate with the Lower Permian (Wolfcampian) *Pseudoalbaillella lomentaria* and *Pseudoalbaillella scalprata* m. rhombothoracata Zones of Ishiga (1986). Age-diagnostic taxa include *Pseudoalbaillella scalprata* morphotype *scalprata* Ishiga and *Pseudoalbaillella scalprata* morphotype *postscalprata* Ishiga (Plate 2). Parts of this same chert trend can be traced across the ridge tops to the south-southwest (Figure 12a), and other bands can be seen approximately half a mile to the southeast.

Begg Member of Vester Formation

According to Dickinson and Thayer (1978), the Begg Member of the Vester Formation (originally Begg Formation of Dickinson and Vigrass, 1965) unconformably overlies the Paleozoic rocks of the Grindstone terrane and represents the oldest rocks in the Izee terrane. The significance of this unconformity for discriminating the Izee from the Grindstone terrane is discussed below. The Begg Member is characterized by chert-grain sandstone, chert-pebble conglomerate, volcaniclastic rocks, and sedimentary breccia, intercalated with equal or greater amounts of mudstone and siltstone.

A small road cut 0.4 mi west of the unnamed chert locality exposes conglomerate containing well-rounded, fusulinacean-bearing cobbles derived from the Coyote Butte limestone unit (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle). This conglomerate has a clast composition similar to limestone-rich conglomerate exposed on Big Flat in the Izee terrane to the east (Figure 13a; loc. 46 of Blome and Nestell, 1991).

Rare exposures of volcaniclastic siltstone and sandstone of unknown age are exposed between Grindstone and Twelvemile Creeks. These exposures are generally unresistant, dark colored (gray to green), locally chert-grain rich, and exposed only in drainages and road cuts. A small exposure of volcaniclastic sandstone can be seen in the same small road cut (Figure 13b).

The precise age of the Begg Member is not known, but it has been tentatively assigned to the Carnian Stage below the late Carnian *Tropites subbulatus* Zone of Smith (1927). The basal part of the member could possibly extend down into the Middle Triassic. Both Mississippian and Permian fossils have been found in limestone and chert boulders and pebbles (Dickinson and Thayer, 1978; Blome and others, 1986). Faunal data presented in Blome and Nestell (1991) showed that most, if not all, of the conglomerate and volcaniclastic rocks scattered throughout the Grindstone terrane are assignable to the Upper Triassic Vester Formation.

En route

From Stop 7, backtrack 0.3 mi to Y-intersection, proceed southwest 1.0 mi to Y-intersection, turn right (northwest) to remains of

Figure 12a.

Figure 12b.

Figure 13a.

Figure 13b.

Figure 14a.

Figure 14b.

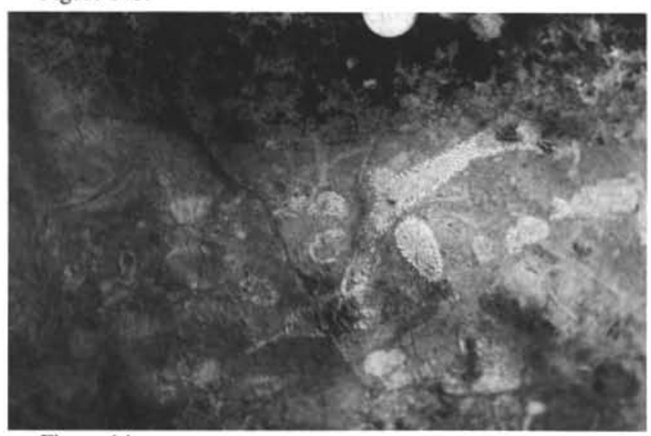

Figure 14c.

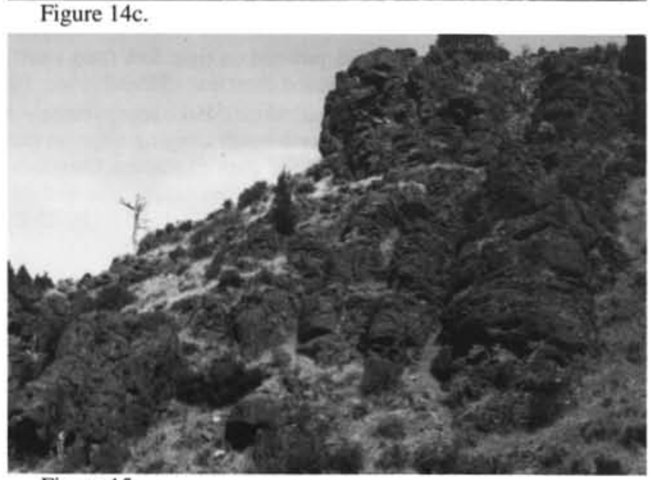

Figure 15.

Facing page, first left, then right column from the top down:

Figure 12a. Exposure of unnamed Lower Permian chert at Stop 7, northern part of the Grindstone terrane, view toward southwest (loc. 2 of Blome and Reed, 1992). Similar chert exposures crop out along the ridge tops in background of photo.

Figure 12b. Closeup of resistant chert exposure shown in foreground of Figure 12a. Photo taken facing northwest.

Figure 13a. Well-rounded cobble of fusulinacean-bearing limestone in Begg Member (Vester Formation) conglomerate on Big Flat (loc. 46 of Blome and Nestell, 1991). Conglomerates similar to this can be seen at Stop 7 in small road cuts and adjacent hill just west of the unnamed chert exposure (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle).

Figure 13b. One of the rare exposures (loc. 19 of Blome and Nestell, 1991) of volcaniclastic sandstone surrounded by less resistant mudstone. Exposure along road just west of unnamed chert at Stop 7, northern Grindstone terrane (center of sec. 10, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle).

Figure 14a. Large block of the coral- and conodont-bearing unnamed Middle Devonian limestone exposed at Stop 8, west side of South Fork Trout Creek, northern Grindstone terrane. View toward southwest from top of ridge containing Upper Triassic Begg Member conglomerate.

Figure 14b. East side of unnamed Middle Devonian limestone exposure at Stop 8.

Figure 14c. Closeup of unnamed Middle Devonian limestone surface, east base of exposure in Figure 14a. Large fossils in photo are corals (coin for scale).

Figure 15. Typical exposure of chert-rich Begg Member (Vester Formation) conglomerate exposed at Stop 9, just off highway northeast of Suplee, west side of four-wheel-drive road.

Birdsong Ranch (building burned), and park for Stop 8: Unnamed Devonian limestone (NE¼NW¼ sec. 16, T. 18 S., R. 25 E., Suplee 7.5′ quadrangle). Hike northwest along drainage for approximately 0.8 mi to large Devonian limestone exposure just west of the South Fork of Trout Creek. Exposures of the Coffee Creek limestone unit can be seen immediately east of drainage on lower slopes, and scattered small outcrops of the Coyote Butte limestone can be viewed to the southeast along ridge crests.

STOP 8—UNNAMED DEVONIAN LIMESTONE, NORTHERN GRINDSTONE TERRANE

Kleweno and Jeffords (1961) described the larger northern exposure of the unnamed Devonian limestone (Figures 14a and 14b; unit Dl in Figure 2) as approximately 100 ft (30 m) of highly folded, massive, cherty limestone with associated cherty breccia and sandstone overlain by chert and argillite. The contact between the limestone and chert appears gradational, but the contact with the adjacent sandstone is sharp and assumed to be unconformable. This outcrop has been informally referred to as the Birdsong limestone by Danner (1977).

The megafossil fauna from the Devonian limestone includes Middle Devonian corals (Figure 14c), stromatoporoids, and brachiopods (Kleweno and Jeffords, 1961; Danner, 1967; Sorauf, 1972; Poole and others, 1977). Additional brachiopod genera (*Schizophoria* and *Emanuella*) and conodonts of Middle Devonian (Givetian) age were also found in this limestone block (Johnson and Klapper, 1978). Savage and Amundson (1979) noted that conodonts from this locality possess a conodont color alteration index (CAI) of 3, which corresponds to a temperature range of 110°-200° C (Epstein and others, 1977). Conodonts recovered from the Permian Coyote Butte limestone unit have CAIs of 1.5-2 (50°-140° C).

En route

Backtrack to Crook County Road 318 and north to Paulina-Izee road. Turn east toward Izee, go 3.5 mi to hairpin turn, and park for Stop 9: Begg Member conglomerate, Vester Formation (central part and NE¼ sec. 20 and SW¼ sec. 17, T. 17 S., R. 26 E., Suplee 7.5′ quadrangle; conglomerate exposed on both sides of highway and just beyond locked gate east and west of dirt road).

STOP 9—BEGG MEMBER OF THE VESTER FORMATION, WESTERN IZEE TERRANE

Traveling east toward the town of Izee, one can see weathered chert-grain sandstone and chert-pebble conglomerate exposures along the highway. Large outcrops of conglomerate assigned to the Vester Formation are exposed just 0.25 mi to the north along the west side of a four-wheel-drive (private!) road (Figure 15; Dickinson and Vigrass, 1965). The high chert-pebble content of the conglomerate at this stop is typical of most Begg conglomerate exposures.

En route

Continue on Paulina-Izee road toward Izee for approximately 9.3 mi to Dayville turnoff. Continue southeastward toward Izee for another 0.9 mi and park for Stop 10: Brisbois Member of the Vester Formation (SW¼ sec. 10, T. 17 S., R. 27 E., Izee 7.5′ quadrangle; Brisbois Member exposed along the north side of highway for another 0.5 mi).

STOP 10—BRISBOIS MEMBER ROCKS, VESTER FORMATION, WESTERN IZEE TERRANE

The Brisbois Member of the Vester Formation (Dickinson and Thayer, 1978; originally the Brisbois Formation of Dickinson and Vigrass, 1965) consists of thin-bedded mudstone and siltstone and intercalated, thin-bedded, gray to black siliciclastic sandstone and sandy calcarenite. Typical Brisbois Member mudstone exposures are visible in a series of road cuts along the highway from Suplee to Izee, beginning approximately 1 mi east from the turnoff to Dayville. Faulted and folded Brisbois exposures can be viewed 1.6 mi southeast of Stop 10 along the highway to Izee (SE¼ sec. 15, T. 17 S., R. 27 E., Izee 7.5′ quadrangle; Figure 16).

Calcarenite beds of the Brisbois Member contain shallow-water brachiopod, bivalve, gastropod, and crinoid fragments. Other bivalves (*Halobia* sp.) and ammonites collected throughout this member are interpreted as being derived from displaced limestone blocks. The ammonites collected from the Brisbois are all indicative of the upper Carnian *Tropites subbulatus* Zone (Dickinson and Vigrass, 1965). Other late Carnian halobiids (*Halobia* cf. *H. ornatissima* Smith) from the upper part of the Brisbois Member were reported by Blome (1984).

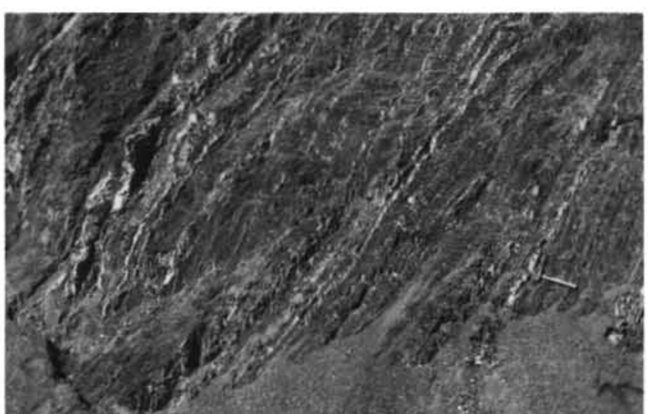

Figure 16. Faulted and folded, thin-bedded mudstone and siltstone of the Brisbois Member (Vester Formation) exposed southeast of Stop 10, approximately 2.5 mi east of turnoff to Dayville along paved highway west of Izee.

En route

From Stop 10, continue eastward for approximately 7.0 mi through Izee to Y-intersection. Take left (northeast) fork toward U.S. 395 and go for another 6.8 mi to Deer Creek Road (NFS 6730). Turn southwest onto forest service road, go 0.3 mi to sharp bend, and park for Stop 11: Snowshoe Formation (SW¼SW¼ sec. 6, T. 17 S., R. 29 E., Lewis Creek 7.5′ quadrangle; exposure just northeast of gravel road).

STOP 11—SNOWSHOE FORMATION EAST OF IZEE

The Snowshoe Formation, established by Lupher (1941) for a sequence of well-bedded siltstone and mudstone with minor sandstone, conformably overlies the Hyde Formation and underlies the Trowbridge Formation along the South Fork of the John Day River near the town of Izee (shown as Jurassic volcaniclastic rocks in Figure 3). Here the Snowshoe Formation was divided into three informal members by Dickinson and Vigrass (1965). The lower member is characterized by brown, gray, or black, thin-bedded mudstone, shale, and siltstone. It also contains ammonite impressions and the bivalve *Posidonia* on bedding partings as well as lenses of silty limestone and dark-gray carbonate concretions. The middle member contains gray to black shale and mudstone intercalated with gray to green volcaniclastic siltstone and fine-grained sandstone. The upper member is typified by thin-bedded mudstone and siltstone with thick intercalations of gray calcareous sandstone. Smith (1980) formally named the lower member the Warm Springs Member, and the middle and upper members the Schoolhouse and South Fork Members, respectively. The sedimentary structures in the coarser grained Snowshoe volcaniclastic rocks indicate deposition in midfan or suprafan lobes within slope to base-of-slope depositional settings (Blome and Nestell, 1991, p. 1292).

A typical Snowshoe Formation exposure can be seen on NFS Road 6730 just west of the intersection with State Highway 63 (Izee-John Day road) along Bunton Creek. This exposure (OR-523 of Pessagno and Blome, 1980, 1982; Pessagno, Six, and others, 1989), which is assigned to the middle member of the Snowshoe Formation (now the South Fork Member of Smith, 1980), is composed of dark-gray mudstone, interbedded graywacke, and gray micritic limestone concretions containing well-preserved silicified radiolarians (Superzone 1, Zone 1C of Pessagno, Blome, and others, 1987) assignable to the middle Bajocian *Otoites sauzei* standard ammonite zone (Imlay, 1973). This overturned section overlies the Silvies Member of the Snowshoe Formation. The underlying lower 200 ft (60 m) of the lower member (equivalent to part of the Warm Springs Member of Smith, 1980) near Izee contains late Toarcian and early Bajocian (Aalenian) ammonite faunas (Imlay, 1973). Other radiolarian faunas and ammonites from Schoolhouse Gulch, immediately north of Izee (Figure 2; Pessagno, Blome, and others, 1987), indicate that the lower part of the Warm Springs Member is assignable to the middle and upper Toarcian and that the remainder of the member is Aalenian (lower Bajocian of Imlay, 1973) and lower Bajocian (= middle Bajocian of Imlay, 1973).

En route

Return to paved road, turn left and travel 16.8 mi to U.S. 395. Turn right (south) and go 7.5 mi on U.S. 395 to town of Seneca. Continue 1.0 mi south of Seneca and park for Stop 12: Undifferentiated Snowshoe Formation (SW¼ sec. 2, T. 17 S., R. 31 E., Silvies 7.5′ quadrangle; exposed on north side of highway).

STOP 12—UNDIFFERENTIATED SNOWSHOE FORMATION, SENECA

This conspicuous exposure of Snowshoe Formation rocks (Figure 17) contains dark-gray mudstone with abundant small, radiolarian-bearing micritic limestone concretions and minor graywacke beds.

Figure 17. Dark-gray mudstone exposure (Stop 12) of undifferentiated Snowshoe Formation containing minor graywacke and ammonite- and radiolarian-bearing limestone concretions (north side of U.S. 395 just south of Seneca).

These rocks rest unconformably(?) beneath massive conglomerate and graywacke of the basal part of the Silvies Member (Snowshoe Formation). The ammonite assemblage from this locality (Pessagno, Whalen, and Yeh, 1986, p. 48) contains *Leptosphinctes* Buckman and *Megasphaeroceras rotundum* Imlay and is assignable to the upper Bajocian Rotundum Zone or its European equivalents (Pessagno, Six, and others, 1989). Well-preserved Late Bajocian radiolarian assemblages from limestone concretions (locs. OR-549A-C) have been described and illustrated by Pessagno and Blome (1980, 1982), Pessagno and Whalen (1982), and Pessagno and others (1986, 1989).

En route

Proceed north on U.S. 395 (toward John Day), go 5.3 mi to first exposures of the Laycock Graywacke, and park for Stop 13: Laycock Graywacke (SW¼ sec. 11 and N½ sec. 15, T. 15 S., R. 31 E., Canyon Mountain 7.5′ quadrangle. No photo was included due to the monotonous and repetitive nature of the graywacke exposed for several miles along U.S. 395).

STOP 13—UPPER TRIASSIC LAYCOCK GRAYWACKE

The rocks of the Aldrich Mountains Group (Fields Creek Formation, Laycock Graywacke, Murderers Creek Graywacke, and Keller Creek Shale) are restricted to the east side of the Poison Creek Fault system (Brown and Thayer, 1966). The Laycock Graywacke is composed of volcaniclastic and tuffaceous sandstone (graywacke of Brown and Thayer, 1977), shale, and conglomerate, some of which is reworked (Dickinson and Thayer, 1978). Extensive exposures of the Laycock can be studied in north-facing road cuts along U.S. 395 just south of Vance Creek (Brown and Thayer, 1977). The Late Triassic age of the Laycock is inferred by its stratigraphic position between the underlying Upper Triassic Fields Creek Formation and overlying Lower Jurassic Murderers Creek Graywacke.

En route

Continue northward approximately 12 mi to town of John Day. From the intersection of U.S. Highways 395 and 26 (center of John Day), turn east, and proceed 2.6 mi to the turnoff to Dog Creek, which makes a sharp angle back to the west. Continue south 1.3 mi on the Dog Creek road until the paved road makes a sharp turn to the right (west). Continue straight across the cattle guard, bearing to the right where the road forks, and then through the gate. Continue 0.7 mi to the road-metal pit on your left and park for Stop 14: Little Dog Creek locality, western Baker terrane (SW¼SE¼ sec. 32, T. 13 S., R. 32 E., John Day 7.5′ quadrangle; exposure on northeast side of ranch road). **Permission must be obtained to venture off the Dog Creek road.**

STOP 14—LITTLE DOG CREEK LOCALITY, WESTERN BAKER TERRANE

Chert and limestone similar to that found in the type area of the Elkhorn Ridge Argillite in the eastern part of the Baker terrane can also be found north of the Aldrich Mountains, both southeast of John Day and near the town of Mount Vernon. In the Baker terrane, limestone and chert are rarely seen in contact with one another because of tectonic disruption, but such a contact is preserved in a road-metal pit (Figures 18a and 18b) on Little Dog Creek a few miles southeast of John Day. Serpentinite and pyroxenite can also be found to the east of the pit on the east slopes of the ridge separating Little Dog and Dog Creeks. Chromite has been mined at several sites along Little Dog Creek.

Although biostratigraphic age data are very scarce from rocks in the western part of the Baker terrane, mid-Permian fusulinaceans, and Late Triassic (Carnian and Norian) radiolarians and conodonts have been recovered from the limestone and chert blocks, respectively, at the Dog Creek locality (Nestell and MacLeod, 1984; Blome and others, 1986). Mid-Permian Tethyan fusulinaceans *Neoschwagerina* cf. *N. craticulifera*, rare *Yangchenia* sp. and *Pseudodoliolina* sp. can be found in a pod of metamorphosed limestone breccia at the north end of the pit. Other Tethyan fusulinacean genera (Plate 3) found in limestone pods in this area include *Maklaya, Misellina, Nagatoella, Ascervoschwagerina*, and *Armenina* (Nestell, 1983). These genera have been reported only from faunas confined to the western margin of North America (Thompson and others, 1950; Bostwick and Nestell, 1966; Monger and Ross, 1971; Stevens, 1977).

Contorted and metamorphosed ribbon cherts containing poorly preserved specimens of the Late Triassic radiolarian genera *Capnodoce, Corum, Pachus, Renzium*, and *Xipha* (Plate 4) and the Late Triassic conodont *Epigondolella abneptus* can be seen in the road-metal pit and on the east side of the road in a small road cut (Figure 18c) between the gate and pit. Larger pods of limestone and chert can be seen on east-facing slopes and near the top of the hill to the west of Little Dog Creek (Figure 18d). Much of this limestone is altered to marble, and fossils are scarce.

The limestone pods on Little Dog Creek are of varying sizes (ranging from a few to tens of meters across) and conglomeratic in some areas, and many appear to be "imbedded" in Middle to Late Triassic radiolarian-bearing chert. Carbonate textures range from mudstone to boundstone. Fusulinaceans and algae are the dominant fossil components of the limestones and range in age from latest Wolfcampian to earliest Guadalupian. We interpret the Little Dog Creek limestones as possibly representing fragments of seamounts redeposited into a basinal setting dominated by siliceous sediments. The Little Dog Creek rocks lie on the northern margin of the Canyon

Upper left: *Figure 18a. Mid-Permian fusulinacean-bearing brecciated limestone overlying Upper Triassic radiolarian-bearing chert at Stop 14, small road-metal pit on east side of Little Dog Creek.*

Lower left: *Figure 18b. Contact (at hammer head) in road-metal pit between mid-Permian fusulinacean-bearing brecciated limestone block and Upper Triassic radiolarian-bearing chert (Stop 14).*

Upper right: *Figure 18c. Tightly folded Upper Triassic radiolarian-bearing ribbon chert exposed in east road cut just north of the road-metal pit on Little Dog Creek at Stop 14.*

Lower right: *Figure 18d. Outcrops (west of Stop 14) of mid-Permian limestone blocks containing Tethyan fusulinaceans. Photo taken looking west from ridge above Little Dog Creek (NE¼SW¼ sec. 32, T. 13 S., R. 32 E., John Day 7.5' quadrangle).*

Mountain Complex, which was accreted to North America in the Late Jurassic or Early Cretaceous. The biostratigraphic relationships of the Little Dog Creek limestone and chert to more extensive exposures in the Baker terrane to the northeast will be discussed in a forthcoming paper.

COMPARISON OF GRINDSTONE, IZEE, AND BAKER TERRANE ROCKS

Separation of the Izee and Grindstone terranes by Silberling and others (1984, 1987) was based on the absence of known conformable contacts between their rock units and lack of Paleozoic rocks in the Izee terrane, except for Paleozoic limestone clasts in Begg Member conglomerate. The presence of Begg conglomerate in both terranes indicates that the Grindstone terrane formed at least part of the basement for Izee deposition by Late Triassic time. However, the absence of discernible sedimentary contacts between all Grindstone and Izee exposures studied prevents us from reducing the two terranes to subterrane status (Blome and Nestell, 1991).

We agree with Dickinson and Thayer (1978) that uplift and erosion of Grindstone terrane rocks provided part of the detritus for Izee terrane deposition. The Grindstone terrane conglomerate is lithologically similar to the Izee terrane Begg conglomerate near Wade Butte but differs from Begg conglomerate in the central part of the Izee terrane by containing common Coffee Creek limestone detritus. The Begg conglomerate in the Izee terrane (in the Big Flat area) contains cobbles with a somewhat different Permian fusulinacean fauna (e.g., *Pseudoschwagerina* and *Polydiexodina*) and Late Triassic corals and ammonites (Blome and Nestell, 1991). These faunal contrasts between the Triassic conglomerates of the Grindstone and Izee terranes suggest that either (1) the Begg conglomerate may have had several provenances, or (2) the conglomerates may be of varying ages, with the more extensive Izee Begg Member conglomerate being younger. Other redeposited Permian faunas from conglomerate in both terranes indicate penecontemporaneous sources during Begg deposition (Blome and Nestell, 1991).

The Grindstone terrane contains Middle Devonian, Upper Mississippian, Lower Pennsylvanian, Permian, and Lower Triassic rocks according to floral and faunal (brachiopod, conodont, coral, fusulinacean, and radiolarian) evidence. These rock assemblages are all of low metamorphic (zeolite) grade based on conodonts having CAIs of 3 or less and the presence of fresh zeolite minerals in some of the limestone and volcaniclastic rocks. Furthermore, much of the limestone is unaltered. The Grindstone fusulinacean faunas are all of McCloud Limestone affinity and do not contain Tethyan forms (Blome and Nestell, 1991).

Devonian, Pennsylvanian, and Permian faunas are known from limestone and chert in the Baker terrane, but pre-Late Permian faunas are very rare (Mullen-Morris and Wardlaw, 1986). Baker limestone and chert exhibit tectonic shear fabrics, possess greenschist or higher regional metamorphic grades (conodonts with CAIs of 5 to 6), and are commonly altered to marble and metachert, respectively; the limestone also contains two types of fusulinacean faunas, those containing Tethyan forms and those related to the McCloud Limestone (Nestell, 1983; Miller, 1987; Nestell and Blome, 1988).

Scarce fusulinacean assemblages from small, metamorphosed (greenschist-grade) limestone pods in the west-central part of the Baker terrane (east of Elkhorn Ridge) are coeval with and nearly identical to Coyote Butte faunas in the Grindstone terrane. The exact timing of tectonic inclusion of these limestone blocks into the Baker terrane is difficult to ascertain because in some places, such as the Dog Creek locality and one locality on the east side of the Elkhorn Mountains, Permian fusulinacean-bearing limestone is juxtaposed with coeval or Late Triassic (Carnian to Norian) radiolarian chert blocks (Nestell and MacLeod, 1984; Blome and others, 1986; and Nestell and Blome, 1988). Chert in the Grindstone terrane contains both Permian (late Wolfcampian to Djulfian) and Early Triassic radiolarian and conodont faunas, whereas chert in the Baker terrane contains Late Permian and Late Triassic radiolarians. The presence of Permian Coyote Butte detritus in both Grindstone and Izee Triassic conglomerates and the insertion of Coyote Butte limestone outliers into the western part of the Baker terrane no earlier than Late Triassic time suggest that all three terranes were juxtaposed by the Late Triassic or Early Jurassic (Blome and others, 1986; Blome and Nestell, 1991).

DEPOSITIONAL MODELS FOR GRINDSTONE, IZEE, AND BAKER TERRANE ROCKS

One reason for the varied depositional models proposed for the Grindstone terrane (Buddenhagen, 1967; Dickinson and Thayer, 1978; Wardlaw and others, 1982) is the fact that outcrops in the terrane are scarce and in disarray. For example, the Devonian and Mississippian (Coffee Creek limestone unit) limestone blocks are widely separated from one another, yet the southernmost Devonian limestone is almost in contact with a Triassic limestone pod (Figure 2). Several of the limestone blocks exhibit random strike-dip orientations, and some have overturned lithostratigraphy and biostratigraphy. Also, many of the cherts partly enwrap the individual limestone exposures (e.g., at Three Buttes; Blome and Nestell, 1991).

Dickinson and Thayer (1978) and Dickinson (1979) implied that the Grindstone terrane is part of a large mélange belt (Baker terrane) of dismembered oceanic-crust and island-arc rocks in a tectonic matrix of deformed ocean-floor chert and argillite. The severe structural disruption was inferred to be the result of long-term subduction that lasted through Middle Triassic time. The same authors also interpreted the presence of volcaniclastic and chert-grain detritus in the calcarenites as representing deposition on volcanic edifices and partly on uplifted areas of mélange composed of deformed chert and argillite within an arc-trench gap. According to Dickinson (1979), the presence of both Tethyan and American fusulinacean faunas in his central mélange terrane indicates tectonic juxtaposition of stratal components whose depositional sites were far apart in the Paleopacific.

We do not believe that the Grindstone siliceous rocks represent subducted ocean-floor sediments as suggested by Dickinson and Thayer (1978) and Dickinson (1979) because of several lines of evidence. Typical ocean-floor rocks, such as basalt, are missing from the Grindstone rocks and are restricted to the Baker terrane to the northeast. The only Tethyan faunas within Dickinson's mélange are from rocks in the Miller Mountain mélange area (Figure 3; cf. Nestell, 1983), an area now considered to be part of the Baker terrane (Silberling and others, 1984, 1987). Grindstone limestone and chert exposures lack shear or other deformational fabrics at or near their boundaries with adjacent volcaniclastic rocks, and much of the chert exhibits sedimentary structures indicative of slope to base-of-slope paleoenvironments. Furthermore, the examination of aerial photos shows the bedding of the volcaniclastic rocks between the various limestone and chert exposures to be somewhat continuous but discordant with the boundaries of individual limestone and chert blocks (Blome and Nestell, 1991).

An alternative depositional model for the Grindstone terrane limestones (Blome and Nestell, 1991; their Figure 7a) is that they represent gravity slide and slump blocks that became detached from a carbonate shelf fringing a volcanic knoll or edifice in Permian time. These limestones were redeposited and intermixed with Permian and Lower Triassic base-of-slope to basinal chert and siliceous mudstone and uppermost Permian(?) and Triassic slope to base-of-slope volcaniclastic rocks in a fore-arc basin setting. The eroded carbonate shelf either was situated on a structural high along the trench flank of the fore-arc basin (Dickinson and Seely, 1979) or fringed the arc massif itself. We have not discounted the possibility that the older and more metamorphosed unnamed Devonian limestone became integrated with the other Grindstone rocks through structural disruption.

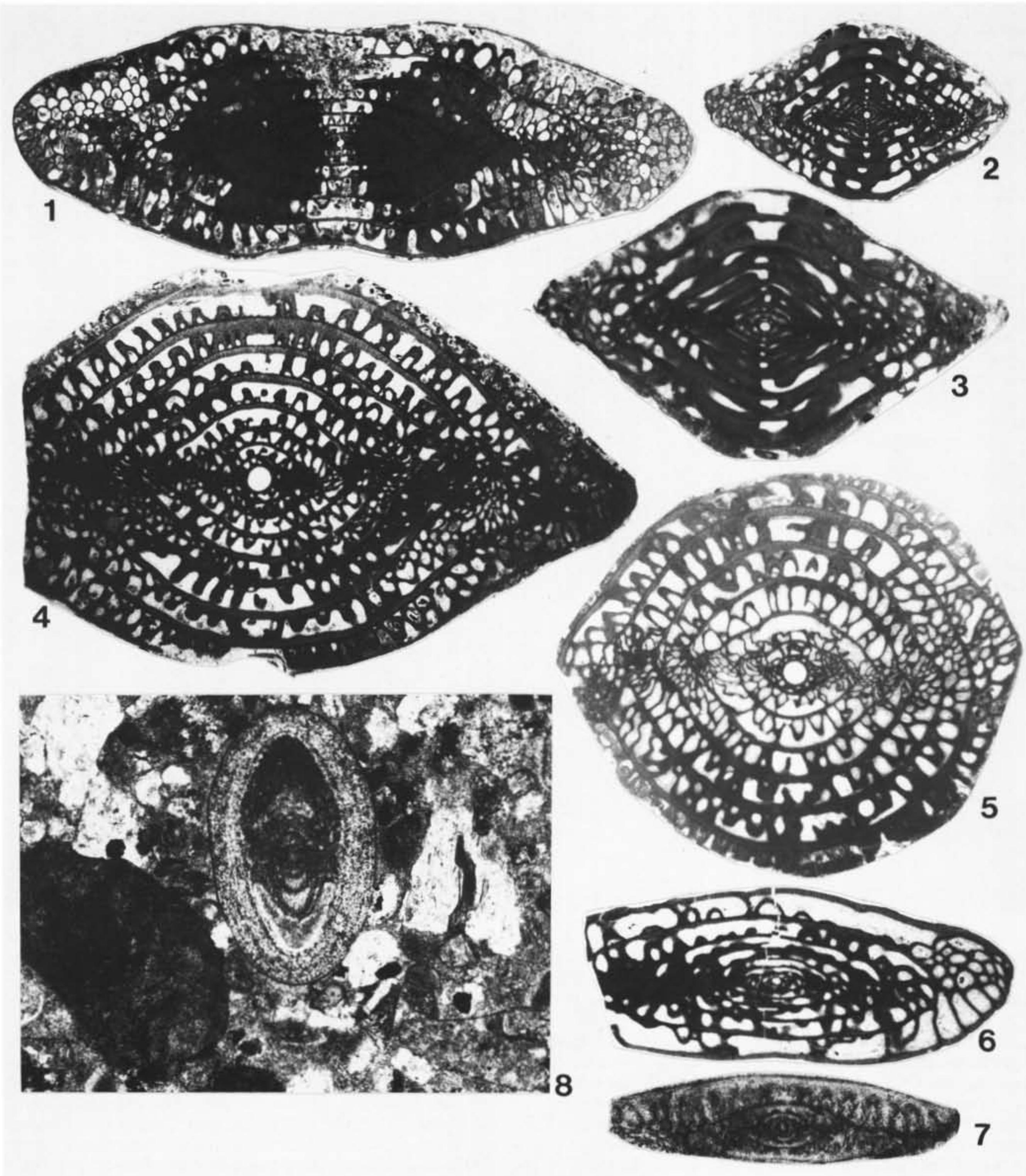

Plate 1. Fusulinaceans from the Grindstone terrane. Specimens 1-6 are reproduced from Skinner and Wilde, 1966. Specimen 7 is from the massive limestone at the east end of Three Buttes. Specimens 1-7 are all from the Coyote Butte limestone unit and are late Wolfcampian in age. Specimen 8 (coated) is Early Pennsylvanian (note the euhedral feldspar in the section) and is from a cobble in the conglomerate in the vicinity of the Coffee Creek limestone unit at Stop 1. 1. *Schwagerina amoena*, x 10; 2. *Pseudofusulinella pinguis*, x 10; 3. *Pseudofusulinella pulchella*, x 20; 4. *Schwagerina oregonensis*, x 10; 5. *Chalaroschwagerina tumentis*, x 10; 6. *Schwagerina minima*, x 20; 7. *Boultonia* sp., x 50; 8. *Nankinella* cf. *N. plummeri*, x 45.

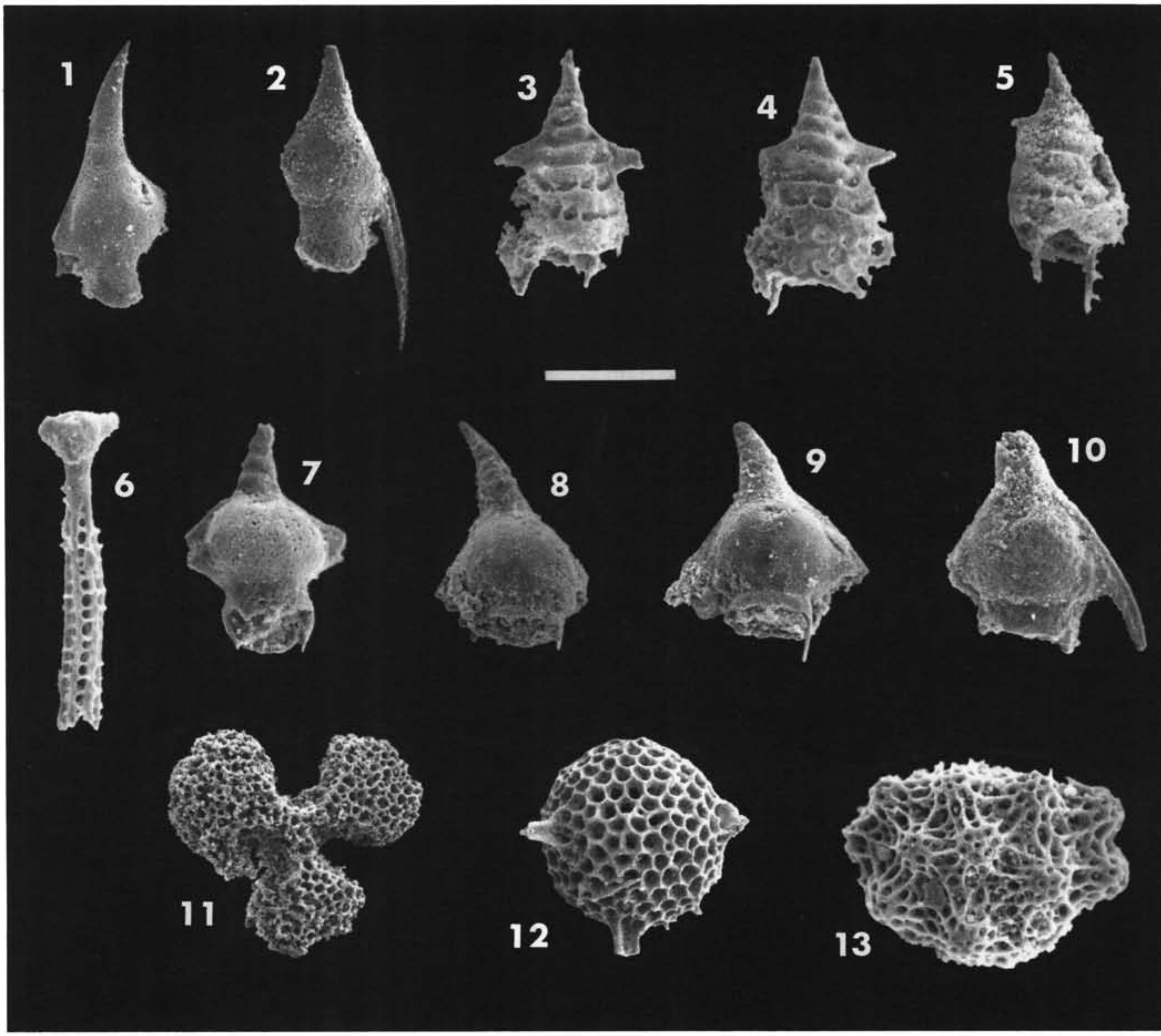

Plate 2. Permian radiolarians from unnamed chert at Stops 4 and 7. 1-2. *Pseudoalbaillella scalprata* morphotype *postscalprata*, both x 120; 3-5. *Albaillella asymmetrica*, x 160, x 200, and x 160 respectively; 6. *Pseudotormentus kamigoriensis*, x 150; 7-8. *Pseudoalbaillella* sp. aff. *P. globosa*, x 150 and x 160, respectively; 9-10. *Pseudoalbaillella scalprata* morphotype *scalprata*, x 160 and x 180, respectively; 11. *Latentifistula* sp. aff. *L. crux*, x 130; 12. *Kashiwara magna*, x 130; 13. *Hegleria mammilla* x 180. Scale bar = 2 cm.

Late Triassic to Middle Jurassic submarine-fan deposits, represented by the Begg Member of the Vester Formation, the unnamed Lower Jurassic limestone and siltstone, and the Snowshoe Formation, subsequently covered the Grindstone deposits (Blome and Nestell, 1991, their Figure 7b). These and other Izee terrane volcaniclastic rock units represent nearly continuous volcaniclastic deposition that infilled the fore-arc basin from Late Triassic through Late Jurassic time (Dickinson and Vigrass, 1965; Dickinson and Thayer, 1978; Dickinson, 1979).

The adjacent Baker terrane to the northeast is a mélange belt of dismembered oceanic crust (e.g., Canyon Mountain Complex; Thayer, 1977) and highly altered limestone, chert, and argillite (Bostwick and Koch, 1962; Vallier and others, 1977). These rocks represent tectonized fragments whose disruption reflects deformation through subduction (Dickinson, 1979; Nestell and Blome, 1988). Both Tethyan and American fusulinacean and coral faunas are found in the Baker terrane limestone.

The tectonic setting for the Grindstone and other eastern Oregon terranes is problematic. Miller (1987) theorized that the Grindstone terrane is part of the McCloud island-arc system that developed above an east-dipping late Paleozoic subduction complex (Burchfiel and Davis, 1981; Miller and Wright, 1987), that complex marginal and foreland basins separated the arc from the continental craton, and that the McCloud island-arc system occupied a back-arc position from Devonian to Permian time (Miller, 1987). However, the contrasts between McCloud Limestone and Grindstone Coyote Butte limestone faunas suggest that the Grindstone terrane and other eastern Oregon terranes may not have been directly linked to the McCloud island-arc system (Blome and Nestell, 1991).

Dickinson (1979) suggested that the Grindstone terrane rocks represent uplifted ridges of mélange (between trench and fore-arc basin) produced by east-dipping subduction in an arc-trench gap. The presence of sedimentary mélange and fore-arc basin rocks in the Grindstone and Izee terranes, respectively (Blome and Nestell,

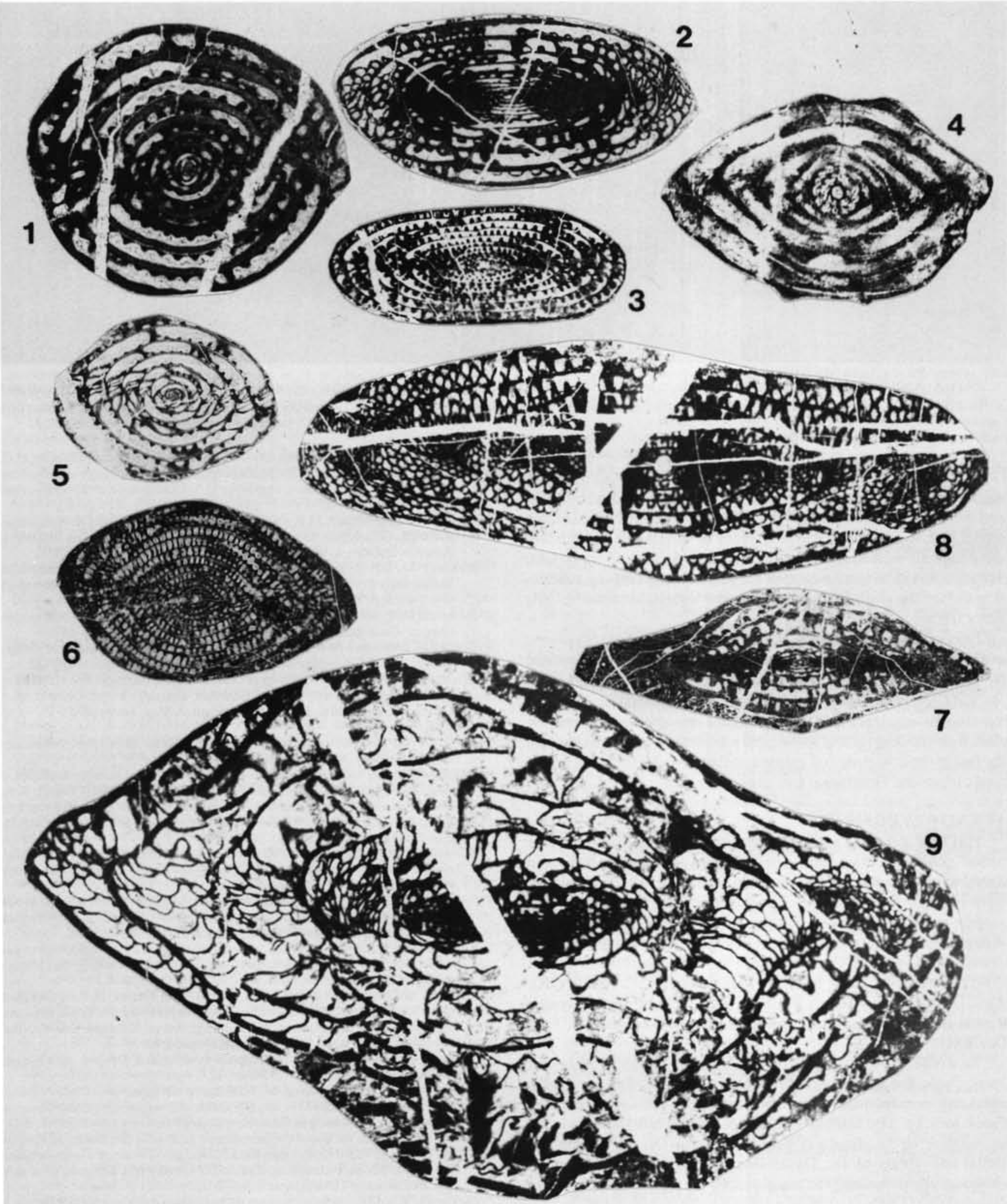

Plate 3. Middle Permian fusulinaceans from the limestone pods on Little Dog Creek. Specimens 1-7 from pods west of creek; 8, 9 from small pod east of creek and above road-metal pit. 1. *Misellina* cf. *M. claudae*, x 20; 2. *Nagatoella* cf. *N. orientis*, x 10; 3. *Pseudodoliolina* sp., x 10; 4. *Yangchenia* sp., x 20; 5. *Armenina* sp., x 10; 6. *Neoschwagerina* sp., x 10; 7. *Chusenella* sp., x 10; 8. *Parafusulina* sp., x 10; 9. *Ascervoschwagerina*(?) sp., x 10. Specimens of the genera 4, 5, and 8 have never been described from North America. Note extensive fractures in some of these forms in contrast to those from the Grindstone terrane.

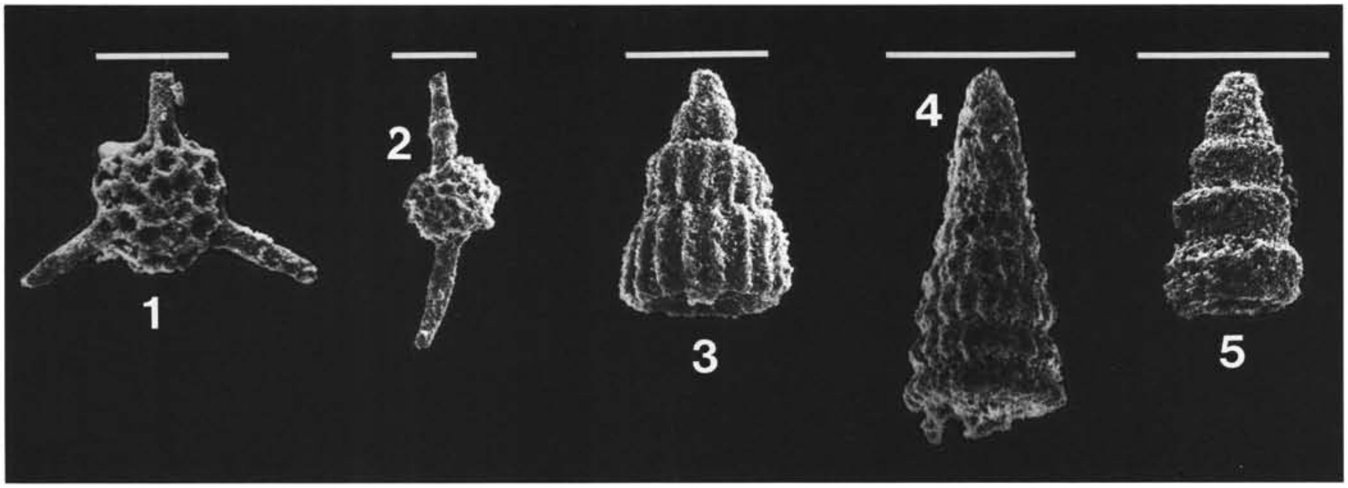

Plate 4. Radiolarians from Late Triassic chert at the Little Dog Creek road-metal pit and adjacent road cut, Stop 14. 1. *Capnodoce antiqua*; 2. *Renzium* sp.; 3. *Xipha pessagnoi*; 4. *Corum speciosum*; 5. *Pachus* sp. Scale bar for Figures 1-4 = 100 microns; bar for Figure 5 = 200 microns.

1991), support an east-dipping subduction model. However, Vallier (1992) and White and others (1992) suggested that a change in convergence direction occurred between the ancient Pacific plate and the Blue Mountains island arc during the Late Triassic. In their model, the Wallowa and Baker terranes developed as an arc/fore-arc pair with west-dipping subduction in Paleozoic to early Late Triassic (early Carnian) time, but a change to east-dipping subduction shifted the axis of volcanism in latest Triassic time to the Olds Ferry terrane.

Paleomagnetic data for the Blue Mountains island arc (Pessagno and Blome, 1986; Vallier and Brooks, 1986) indicate that it has rotated 60° clockwise since the Late Jurassic and/or Early Cretaceous (Wilson and Cox, 1980; Hillhouse and others, 1982). If rotational data for the Grindstone, Izee, and Baker terranes are applicable, counterclockwise rotation back to its original site of deposition would place the Baker oceanic crust and tectonic mélange rocks west and northwest of Izee and Grindstone fore-arc basin rocks.

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MINERAL EXPLORATION

MAJOR MINERAL EXPLORATION ACTIVITY

County, date	Project name, company	Project location	Metal	Status
Baker 1990	Cracker Creek Mine Bourne Mining Corp.	T. 8 S. R. 37 E.	Gold	Expl
Baker 1991	Cave Creek Nerco Exploration	Tps. 11, 12 S. R. 42 E.	Gold	App
Baker 1991	Gold Hill Golconda Resources	T. 12 S. R. 43 E.	Gold	App
Baker 1991	Gold Ridge Mine Golconda Resources	T. 12 S. R. 43 E.	Gold	Expl
Baker 1992	Pole Creek Placer Dome U.S.	T. 13 S. R. 36 E.	Gold, silver	Expl
Baker 1992	Bigelow prospect Yellow Eagle Mining	T. 7 S. R. 45 E.	Gold	Expl
Coos 1991	Seven Devils Oreg. Resources Corp.	Tps. 2, 7 S. R. 4 W.	Chromite, zircon	Expl com
Crook 1988	Bear Creek Independence Mining	Tps. 18, 19 S. R. 18 E.	Gold	Expl
Curry 1992	Mindoro Project Mindoro Corporation	T. 36 S. R. 12½ W.	Precious metals	Expl
Curry 1992*	Myers Creek Quarry Oreg. St. Highw. Div.	T. 38 S. R. 14 W.	Rock	Expl
Grant 1991	Buffalo Mine American Amex	T. 8 S. R. 35½ E.	Gold	App
Grant 1992	Quartzburg Placer Dome U.S.	T. 12 S. R. 33 E.	Precious metals	Expl
Harney 1990	Pine Creek Battle Mtn. Exploratn.	T. 20 S. R. 34 E.	Gold	Expl
Harney 1991	Flagstaff Butte Noranda Exploration	Tps. 3, 9 S. R. 37 E.	Gold	App
Harney 1992	Celatom Mine Eagle-Picher Minerals	Tps. 19, 20 S. Rs. 35-37 E.	Diatoms	App
Jackson 1991	Al Sarena Project Fischer-Watt Gold Co.	T. 31 S. R. 2 E.	Gold	App
Jackson 1992*	Janus Project Kennecott Exploration	T. 39 S. R. 4 W.	Precious metals	Expl
Josephine 1992	Eight Dollar Mountain Doug Smith	T. 38 S. R. 8 W.	Nickel	Expl
Lake 1988	Quartz Mountain Wavecrest Resources.	T. 37 S. R. 16 E.	Gold	Expl
Lake 1990	Glass Butte Galactic Services	Tps. 23, 24 S. R. 23 E.	Gold	Expl
Lake 1991	8th Drilling Series Wavecrest Resources	T. 37 S. R. 17 E.	Gold	Expl
Linn 1991	Hogg Rock Oreg. St. Highw. Div.	T. 13 S. R. 7½ E.	Rock	App
Malheur 1988	Grassy Mountain Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Expl, com
Malheur 1988	Jessie Page M.K. Gold Co.	T. 25 S. R. 43 E.	Gold	Expl
Malheur 1988	Kerby Malheur Mining	T. 15 S. R. 45 E.	Gold	Expl, com
Malheur 1989	Hope Butte Chevron Resources	T. 17 S. R. 43 E.	Gold	Expl, com
Malheur 1990	Ali/Alk Atlas Precious Metals	T. 17 S. R. 45 E.	Gold	Expl
Malheur 1990	Cow Valley Butte Cambiex USA, Inc.	T. 14 S. R. 40 E.	Gold	Veg

MAJOR MINERAL EXPLORATION ACTIVITY (continued)

County, date	Project name, company	Project location	Metal	Status
Malheur 1990	Goldfinger Site Noranda Exploration	T. 25 S. R. 45 E.	Gold	Expl
Malheur 1990	Grassy Mtn. Regional Atlas Precious Metals	T. 22 S. R. 44 E.	Gold	Veg
Malheur 1990	Katey Claims Atlas Precious Metals	Tps. 24, 25 S. Rs. 44, 46 E.	Gold	Expl
Malheur 1990	Mahogany Project Cyprus Minerals	T. 26 S. R. 46 E.	Gold	App
Malheur 1990	Racey Project Ican Minerals, Ltd.	T. 13 S. R. 41 E.	Gold	Expl
Malheur 1990	Sand Hollow Noranda Exploration	T. 24 S. R. 43 E.	Gold	Veg
Malheur 1990	Stockade Mountain BHP-Utah Internatl.	T. 26 S. Rs. 38, 39 E.	Gold	Expl
Malheur 1990	Stockade Project Phelps Dodge Mining	Tps. 25, 26 S. R. 38 E.	Gold	Expl
Malheur 1991	Bannock Atlas Precious Metals	T. 25 S. R. 45 E.	Gold	Veg
Malheur 1991	Quartz Mtn. Basin BHP-Utah Intl., Inc.	T. 24 S. R. 43 E.	Gold	App
Malheur 1991	Rhinehardt Site Atlas Precious Metals	Tps. 18, 19 S. R. 45 E.	Gold	Veg
Malheur 1991	White Mountain D.E. White Mtn. Mining	T. 18 S. R. 41 E.	Diatoms	App
Malheur 1992*	Deer Butte Atlas Precious Metals	T. 21 S. R. 45 E.	Gold	Expl
Malheur 1992	Shell Rock Butte Ronald Willden	T. 21 S. R. 44 E.	Gold, silver	App
Malheur 1992*	Swamp Creek Carlin Gold Co.	T. 25 S. R. 38 E.	Gold	Expl
Marion 1990	Bornite Project Plexus Resources	T. 8 S. R. 3 E.	Copper	App com

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

The announced sale of Atlas Precious Metals Grassy Mountain project to Newmont Mining Corporation was completed during the month of October.

A Draft Environmental Impact Statement for the Plexus Bornite copper mine project in Marion County should be available from the Detroit Ranger District of the Willamette National Forest by mid-November.

Questions or comments should be directed to Gary Lynch or Allen Throop in the Mined Land Reclamation Office of the Oregon Department of Geology and Mineral Industries, 1536 Queen Avenue SE, Albany, OR 97321, telephone (503) 967-2039, FAX (503) 967-2075. □

Correction

In the field trip guide "Natural hazards of the Pacific Northwest" by Charles L. Rosenfeld, an article that appeared in the July issue of *Oregon Geology*, Figure 4 on page 78 should have been attributed to Richard B. Waitt, Jr., who published it in 1985 in his paper "Case for periodic, colossal jökulhlaups from Pleistocene glacial Lake Missoula," GSA Bulletin, v. 96, no. 10, on page 1272. We apologize for the oversight. *—ed.*

New-edition *Geology of Oregon* has a new look

After we offered our readers a taste of the first chapter in the last issue of this magazine, we now take pleasure in announcing the appearance of the whole book—the all-new fourth edition of *Geology of Oregon*:

Geology of Oregon, 4th ed., 1992, by Elizabeth L. Orr, William N. Orr, and Ewart M. Baldwin, published by Kendall/Hunt Publishing Company, ISBN 0-8403-8058-5, 254 p., $25.

Over 28 years, this standard of comprehensive information on the geology of the state for both students and amateurs in the field was seen through three editions by its original author Ewart Baldwin, now emeritus professor of the University of Oregon. In the fourth edition, Baldwin now shares authorship with Elizabeth Orr, a research librarian, and her husband, William Orr of the University of Oregon Department of Geological Sciences.

The Orrs have already become known to the geologically interested public with such books as *Handbook on Oregon Plant and Animal Fossils* (1981), *Bibliography of Oregon Paleontology* (1984), and *Rivers of the West* (1985). Their contribution to *Geology of Oregon* indeed makes this an "all-new" edition—completely rewritten and 50 percent longer than the last edition.

In comparison to the previous editions, efforts have been increased to make this book useful for those without scientific and geologic training—as well as for the experts. The diversity and complexity of Oregon's geology therefore required a certain degree of generalization and simplification in presenting a great deal of "technical" information and the conclusions that have been drawn from it.

While the original organization—treating the state's physiographic provinces one by one—was retained, the approach is changed to place the emphasis on tectonics and paleoenvironments (rather than stratigraphy). The book thus reflects a significant body of information that has come to light only in recent years and uses it to present a dramatic account of how Oregon was built and changed as a part of the North American continent. A "user-friendly" look is achieved also by the addition of many three-dimensional block diagrams and drawings that reconstruct plants and animals from fossils—less technical in appearance than the usual graphic illustrations but just as informative.

A brief introductory chapter sketches in broad strokes the creation of the land that Oregon occupies today and stimulates the reader's appetite to learn more. A similarly brief chapter follows, describing the development of geological study of the state and of geologic sciences in Oregon. The sequence of chapters on individual physiographic provinces follows the pattern in which the edge of the continent moved west toward the position of today's coastline. Each of these chapters concludes with a brief list of suggested readings, while at the very end a voluminous bibliography (21 pages) provides a wealth of references. A glossary of technical terms and a subject index round off a book of which one enthusiastic early reader, Portland State University Emeritus Professor John E. Allen, wrote us that "It will be many years before a fifth edition is justifiable."

The new book is available from the regional distributors, Orr Publishers, P.O. Box 5286, Eugene, OR 97405. It can also be purchased over the counter, by mail, phone, or FAX for $25, plus $3 for mailing from the Nature of Oregon Information Center of the Oregon Department of Geology and Mineral Industries, Suite 177, 800 NE Oregon Street, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; or from the Department's field offices in Baker City, 1831 First Street, Baker City, Oregon 97814, phone (503) 523-3133, FAX (503) 523-9088; and Grants Pass, 5375 Monument Drive, Grants Pass, Oregon 97526, phone (503) 476-2496, FAX (503) 474-3158. □

THESIS ABSTRACTS

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

Longshore grain sorting and beach-placer formation adjacent to the Columbia River, by Zhenlin Li (Ph.D., Oregon State University, 1991), 232 p.

The formation of beach placers primarily involves processes of waves and currents that selectively sort and concentrate the valuable minerals according to their densities, sizes and shapes. Black sand placers are found on the beaches adjacent to the mouth of the Columbia River. Reviews of historical shoreline changes show that jetty construction has caused rapid beach accretion immediately adjacent to the river mouth, and thus is important to the placer development. Beach-face sand samples were collected along 70 km of shoreline north and south from the river mouth and were analyzed to determine the sorting processes responsible for the formation of this placer. It is found that heavy minerals are highly concentrated close to the Columbia River mouth, reaching 60 percent to 70 percent on the summer beach, and in excess of 90 percent during the winter. The concentration decreases systematically with longshore distance, being reduced to less than 2 percent after 20 km of longshore transport from the river mouth. The median grain sizes of principal minerals generally become finer with longshore distance, but an away-from-source coarsening is found within 5-8 km of the river mouth. These analyses indicate that the Columbia River is the major sediment source for these beaches. The sand is transported alongshore north and south away from the river mouth. Though normal grain sorting and sediment transport processes are important for most parts of the beaches, selective grain sorting and transport processes are dominant immediately adjacent to the river mouth.

Calculations of hydraulic ratios for various mineral pairs show that the longshore transportability of heavy mineral increases with its relative grain size and decreases with its density. This suggests that the heavy minerals of higher densities and finer grain sizes are less easily transported alongshore and are more concentrated close to the river mouth. Settling velocity measurements show that sorting due to contrasting settling rates could be responsible for the overall separation of the heavy minerals from the light minerals but cannot explain the separation of individual heavy minerals. Evaluations of selective entrainment stresses and bedload transport rates and results of the flume experiments show that minerals requiring higher selective entrainment stresses and with resulting lower bedload transport rates are those most concentrated in the placer deposits. This suggests that selective entrainment and differential transport sorting processes have been most important in the formation of the placer deposits adjacent to the Columbia River.

Structure and tectonics of the southern Willamette Valley, Oregon, by Erik P. Graven (M.S., Oregon State University, 1991), 119 p.

Surface geology, seismic data, petroleum exploratory well data, and water well data have been used to analyze the structural and tectonic history of the southern Willamette Valley. Tertiary strata beneath the southern Willamette Valley appear to have had an early Cascade or Clarno volcanic source to the east by the middle Eocene. The Tertiary strata have been deformed into a series of broad north-northeast-trending folds and northeast- and northwest-trending faults which initially developed under east-northeast compression during the middle Eocene and have since been rotated clockwise to their present positions. The cross-cutting pattern of subsurface faults has been complicated by reactivation during the clockwise rotation of S_1 to its present orientation of north-south. Uplift of the

Coast Range prior to emplacement of the Miocene Columbia River Basalt Group (CRBG) produced the gentle east dip of strata beneath the western edge of the Valley and beneath the CRBG in the Salem and Eola Hills.

The southern Willamette Valley is controlled by erosion of the relatively incompetent Eugene Formation following emplacement of CRBG. Neogene sediments deposited after this degradation event suggest that during the late Miocene to Pliocene the proto-Willamette River flowed east of the Salem Hills before uplift along the Waldo Hills forced its course to the west. This aggradation appears to have been caused by increased uplift of the Coast Range and/or subsidence of the Willamette Valley over the slab bend in the subducting Juan de Fuca Plate. Degradational and aggradational periods during the Pleistocene appear to have been caused by readjustment of the Willamette River system to new base levels and changes in sediment supply to the valley.

Neotectonic features in the valley include (1) the Owl Creek fault which is at least Pleistocene in age and possibly younger, (2) the Harrisburg anticline, (3) the Turner fault, and (4) deformation in the North Santiam River Basin including the Mill Creek fault. With the exception of the Owl Creek fault, the minimum age of these structures is poorly constrained but is at least post-Miocene and possibly younger.

Geology and hydrothermal mineralization in the vicinity of Rocky Top, Marion County, Oregon, by John M. Curless (M.S., Oregon State University, 1991), 111 p.

The Rocky Top area is located within the Western Cascades subprovince of Oregon, approximately 65 km east-southeast of Salem. Late Oligocene- to late Miocene-age volcanic rocks exposed within the area form an impressive 3,000-m-thick stack of calc-alkaline volcanic rocks which locally records subsequent events of tectonic deformation, magmatic intrusion, and hydrothermal mineralization. Pliocene to Pleistocene volcanic rocks in the Rocky Top area are unaltered, chemically distinct, and found as intracanyon flows into the older rocks.

Plutonic rocks of late Miocene age have been hydrothermally mineralized and are exposed as northwest-trending dikes and small stocks. Their spatial distribution as well as mineralogical, textural, and chemical features indicate that they are related to the nearby Detroit Stock. Early formed quartz diorites at Sardine Creek and Rocky Top are exposed as dikes with sharp to slightly brecciated contacts and were emplaced along pre existing northwest-trending structures. Later hornblende granodiorites, with contacts defined by well-developed intrusive breccias, are exposed as irregularly shaped northwest-elongate dikes and small stocks. Stratigraphic reconstruction from Sardine Creek to Rocky Top suggests that the later hornblende granodiorites were emplaced at a minimum depth of roughly 1 km, with the earlier quartz diorites intruding to shallower levels.

Propylitic alteration is widespread throughout the Rocky Top area and intensifies with proximity to northwest-trending structures. Potassic alteration is limited to within the Detroit Stock, where several samples contain incipient veinlets and diffuse replacement zones of hydrothermal biotite. Late-stage sericitic (sericite-quartz) and argillic (clay-quartz plusmin barite) alteration is characterized by the replacement of groundmass and phenocrysts by sericite or clay minerals, quartz, and pyrite, along with a loss of primary textures, which accompanies mild to strong bleaching of the wall rocks. Late-stage alteration is structurally controlled and overprints earlier propylitic and potassic alteration.

Zones of hydrothermal metallization are narrow and weakly developed and lack evidence of past exploration activity. Sulfide minerals occur as open-space fillings and as disseminations in the volcanic and plutonic rocks. The principal sulfide is pyrite, although sphalerite, chalcopyrite, and galena are locally abundant in small veins and disseminations associated with sericitic alteration. Sulfur isotopic compositions of these minerals range from +2.8 per mil to -3.3 per mill and average about -0.5 per mil. This relatively narrow range of delta 34S values, near 0 per mil, is suggestive of a magmatic origin of sulfur and is consistent with data obtained elsewhere from the Western Cascades. Isotopic temperature estimates from coexisting sphalerite and galena indicate that sulfide deposition occurred at 200°-220°C.

More than 80 rock-chip samples from the Rocky Top, Sardine Creek, and Detroit stock areas have been analyzed for Cu, Pb, Zn, and other trace metals. Concentrations of these metals in samples from the Rocky Top area range up to 16 ppm Ag, 16 ppb Au, 830 ppm Cu, 75 ppm Mo, 1330 ppm Pb, and 3570 ppm Pb, and 3570 ppm Zn. Threshold values dividing background and mineralized samples were determined to be 60 ppm Cu, 30 ppm Pb, and 100 ppm Zn. The relative proportions of these metals in mineralized samples depict a progressive change with increasing horizontal and vertical distance from more Cu (Zn) at the Detroit Stock, through Zn (Cu) at Sardine Creek, to Pb (Zn) at Rocky Top.

Investigation of the interrelationships between mineralization and associated plutonic rocks combined with volcanic stratigraphy, structure, and topography suggests that Rocky Top may be one of the youngest and highest level hydrothermal systems recognized in the Western Cascades. Although plutonism and hydrothermal mineralization in this area have many features in common with nearby mining districts of the Western Cascades, the absence of well-developed breccia pipes, through-going veins, and zones of intense pervasive alteration are consistent with the lack of previous mining activity or extensive exploration.

Petrogenesis of compositionally distinct silicic volcanoes in the Three Sisters region of the Oregon Cascade Range: The effects of crustal extension on the development of continental arc silicic magmatism, by Brittain Hill (Ph.D., Oregon State University, 1991), 235 p.

The Three Sisters region of the Oregon High Cascades has developed three compositionally and petrogenetically distinct silicic (i.e., SiO_2 ≥58 percent) magma systems within the last 600,000 years. These silicic systems evolved from the same High Cascade mafic magma system and developed in the same 20- x 30-km area of the arc, but did not interact. The Broken Top system (BT) evolved to 71 percent SiO_2 through a combination of plag + px + Fe-Ti oxides ± ap (PPFA) fractionation and 20-35 percent mixing of rhyolitic (74 percent SiO_2) crustal melts. In contrast, part of the Three Sisters system (3S) evolved to 66 percent SiO_2 through PPFA fractionation alone, while other parts evolved to 66 percent SiO_2 through PPFA fractionation coupled with ≥40 percent mixing of rhyolitic (≥72 percent SiO_2) crustal melts.

The 3S system was intermittently active from ≤340 ka to 2 ka. The petrogenesis of intermediate composition rocks at Middle Sister (<340 ka, >100 ka) was controlled by PPFA fractionation to ≤66 percent SiO_2. Rhyolite (72-76 percent SiO_2) was first erupted in the 3S system at ~100 ka, at the start of South Sister (SS) volcanism. Major and trace element abundances preclude derivation of 3S rhyolite through crystal fractionation but are consistent with 20-30 percent dehydration melting of mafic amphibolite. The petrogenesis of intermediate composition rocks at SS was controlled PPFA fractionation coupled with 30-40 percent rhyolitic magma mixing. However, the rhyolitic magma mixed into an essentially mafic system, which limited intermediate differentiation at SS to ≤66 percent SiO_2.

The BT system was active from ~600 ka to at least 200 ka. Major and trace element abundances preclude derivation of BT rhyolite (74 percent SiO_2) through crystal fractionation but are consistent with ~30 percent dehydration melting of older tonalitic intrusions. BT petrogenesis was controlled by PPFA fractionation accompanied by 10-20 percent mixing of rhyolitic magmas to ~63 percent SiO_2, with ~30 percent rhyolite mixing from 63-71 percent SiO_2. In contrast to the 3S system, differentiation proceeded beyond 66 percent SiO_2 because rhyolitic magma was mixed into a more evolved (~60-65 percent SiO_2) system.

The observed temporal and spatial variations in petrogenesis were not controlled by regional changes in tectonic setting, crustal thickness or crustal composition. However, small-scale changes in the magnitude of crustal extension occurred in this area, and are thought to have controlled petrogenesis by localizing mid-crustal mafic magmatism and thus crustal heat flow.

Late holocene paleoseismicity along the northern Oregon coast by Mark E. Darienzo (Ph.D,) Portland State University, 1991, 167 p.

Marsh paleoseismological studies were conducted in four bays (Necanicum, Nestucca, Siletz, and Yaquina) along the northern Oregon coast and compared with completed studies in two other bays (Netarts and Alsea). Coseismically buried peats were identified in all bays, based on (1) abrupt contacts, decreases in organic content, increases in sand content, increases in beach sand, and changes in diatom assemblages, all from the peat to the overlying sediments; (2) distinct sandy. layers and key plant macrofossils, such as *Triglochin*, above the buried peat, and (3) widespread correlation of the buried peats within the bay. The stratigraphy and the ages and depths of the top six coseismically buried peats were compared between bays. The following similarities were noted: (1) All bays recorded five burial events in the top 2.6 m within the last 2,200 years. (2) Six burial events were recorded in six bays in the top 3.0 m, except Alsea Bay (3.3 m), and all six events occurred within the last 2,600 years except Yaquina (2,780 years). (3) The depth to the top of each buried peat in the bays is consistent, falling within discrete ranges, except for the to two events at Yaquina. (4) Distinct sandy layers (tsunami-deposited) are present over the topmost buried peat in all bays except Yaquina and over the fourth in all bays except Yaquina and Nestucca. (5) Distinct tsunami-deposited sandy layers are absent over the third buried peat in Netarts, Nestucca, Siletz, Alsea, and possibly Yaquina but present at Necanicum. The evidence strongly suggests synchroneity of coseismic events between the Necanicum River and Alsea Bay (a distance of 175 km), with the exception of the second and sixth event. The sixth coseismic event would be synchronous between Alsea and Netarts, a distance of 105 km. The support for synchroneity of the second event is weak. Synchroneity of coseismic burial events on the northern Oregon coast would argue for paleomagnitudes of at least 8.1 M_w, given a minimum rupture width of 50 km and a rupture length of 105 km. The paleomagnitudes were determined via the moment magnitude equation $M_w=⅔ \log_{10}M_o-10.7$, where M_o=shear modulus x rupture area x seismic slip. The seismic slip is estimated from a minimum recurrence interval of 300 years and.a minimum convergence rate of 3.5 cm/yr.

Geology of the Krumbo Reservoir quadrangle, southeastern Oregon, by Jenda A. Johnson (B.S., Oregon State University, 1992), 56 p.

The geology of the Krumbo Reservoir quadrangle, located on the west side of the Steens Mountain escarpment in southeastern Oregon, consists of a bimodal assemblage of Miocene olivine basalt and rhyolite ash-flow tuff characteristic of northwestern Basin and Range volcanism. The assemblage contains three major stratigraphic markers, the Steens Basalt (approximately 16 Ma), the Devine Canyon Ash-flow Tuff (approximately 9.5 Ma), and the Rattlesnake Ash-flow Tuff (approximately 6.7 Ma). Locally exposed units of limited extent are upper Miocene olivine basalt, emplaced between Devine Canyon and Rattlesnake time, and tuff and tuffaceous sedimentary rocks that underlie the Devine Canyon Ash-flow Tuff. The entire study area is underlain by the chemically homogeneous lava flows of Steens Basalt. The Steens Basalt is unconformably overlain by a sequence as thick as 30 m of tuff and tuffaceous sedimentary strata and, locally, by the Devine Canyon Ash-flow Tuff (maximum thickness 17 m). The basalt of Hog Wallow lies conformably above the Devine Canyon Ash-flow Tuff in the northern part of the map area. The Rattlesnake Ash-flow Tuff, which includes some poorly exposed tuffaceous sedimentary strata at its base, conformably overlies the Devine Canyon Ash-flow Tuff and forms the capping unit in the map area. The ash-flow tuffs form mesas and flat-topped ridges. The rhyolite ash-flow tuffs spread laterally over tens of thousands of square kilometers in southeastern Oregon.

Two different sets of faults form conspicuous escarpments in the map area: north-striking-faults that parallel Basin and Range faults and numerous closely spaced west-northwest-striking faults that parallel the Brothers Fault zone. In the map area, the Devine Canyon Ash-flow Tuff changes map pattern from sheet-forming in the northwest to lobe-forming in the southeast. The elongate erosional remnants of the Devine Canyon Ash-flow Tuff parallel the Brothers Fault zone and probably result from inverted topography as a consequence of thicker deposition of the tuff in paleodrainages. It seems likely that this zone marks the ancient change in slope from flat ground with surface water present on the northwest to better-drained ground south and southeastward. Dutch Oven, a closed depression 1.5 km in diameter, is a relict secondary hydroexplosion crater that formed when the hot Rattlesnake pyroclastic flow interacted with surface water; the resulting steam blasted through the overlying deposits leaving a large pit. At least six such pits are found in the Rattlesnake Ash-flow Tuff in this part of Harney Basin. □

Observatory needs volunteers

The USDA Forest Service, McKenzie Ranger District, of the Willamette National Forest is looking for volunteer interpreters or naturalists to serve at Dee Wright Observatory by the summit of the old McKenzie Highway (Hwy 242) in the Cascade Range.

The volunteer position is to start in June 1993, and volunteers would spend three to six hours a day, three or more days a week between July and October, at the observatory assisting visitors. A shorter time commitment would also be possible. Some knowledge of and interest in geology of the Cascades and history of Oregon would be particularly desirable. Camping in the area is not required, so that volunteers could commute from Sisters, Bend, Eugene, or the McKenzie River corridor.

Plans are to repair the observatory structure and replace interpretive signs in the near future, and volunteers would be helping to decide what information should be provided. Additional opportunities for volunteers will be to develop a guided walk for the existing paved trail through the lava beds at the site and also to serve as campground hosts at either a dispersed camp area (Scott Lake) on Highway 242 or in a campground on Highway 126.

In the Forest Service volunteer program, volunteers are signed up on a volunteer agreement that provides them with coverage for on-the-job accidents. They will be expected to provide their own transportation to the observatory. The agency will negotiate reimbursement of some expenses such as mileage, typically at a rate not exceeding $15 a day and for gasoline. Camping volunteers need to provide their own camping equipment, so owners of recreational vehicles are particularly encouraged to apply.

The agency is flexible with this proposed volunteer arrangement and invites all those who are possibly interested or have questions to call or write Pam Novitzky, Developed-Sites Manager, McKenzie Ranger District, McKenzie Bridge, OR 97413, phone (503) 822-3381. *—USFS release*

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