

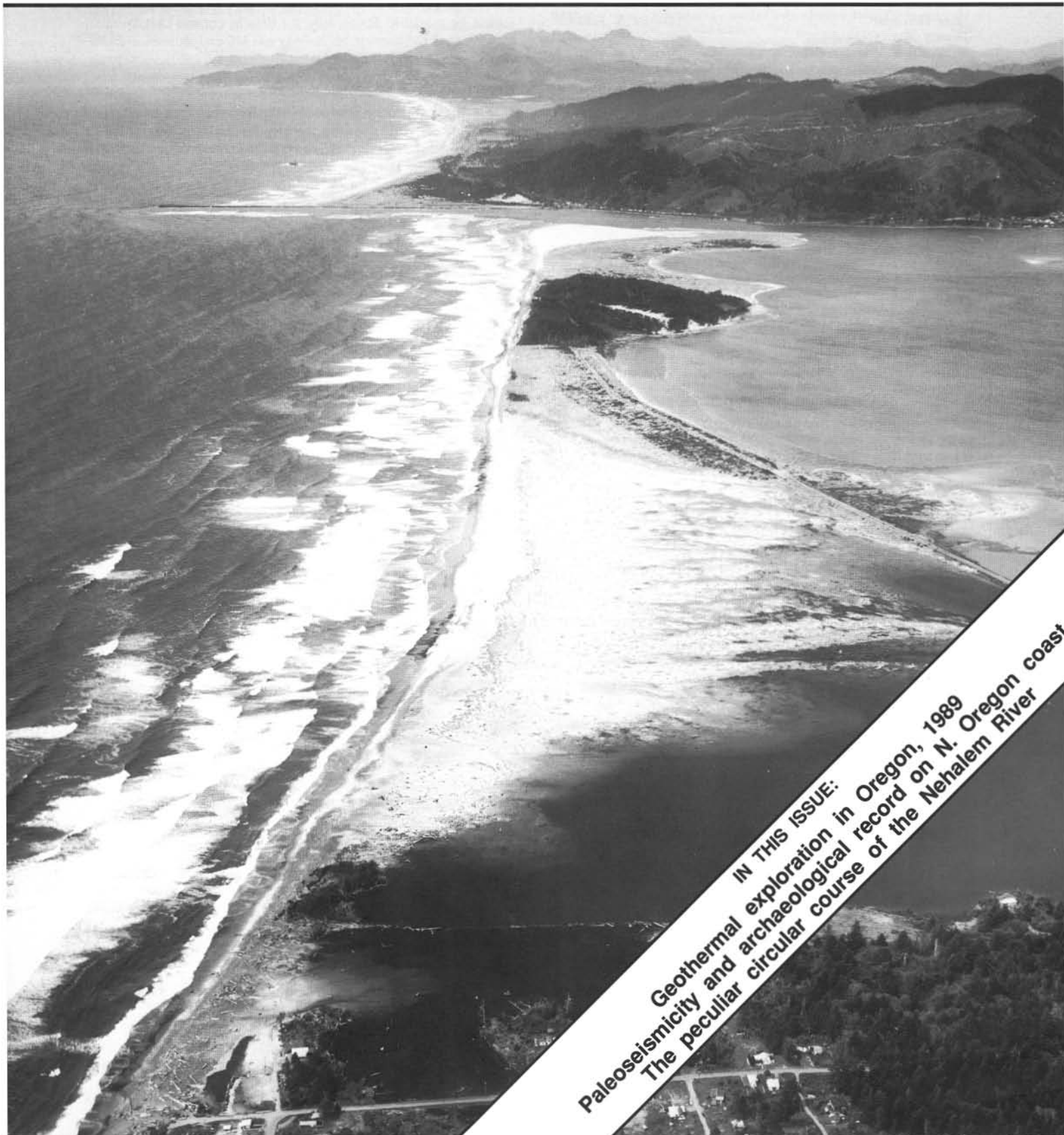
OREGON GEOLOGY

published by the
Oregon Department of Geology and Mineral Industries



VOLUME 52, NUMBER 3

MAY 1990



IN THIS ISSUE:
Geothermal exploration in Oregon, 1989
Paleoseismicity and archaeological record on N. Oregon coast
The peculiar circular course of the Nehalem River

OREGON GEOLOGY

(ISSN 0164-3304)

VOLUME 52, NUMBER 3

MAY 1990

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

Governing Board

Sidney R. Johnson, Chair Baker City
Ronald K. Culbertson Myrtle Creek
Donald A. Haagensen Portland

State Geologist Donald A. Hull

Deputy State Geologist John D. Beaulieu

Publications Manager/Editor Beverly F. Vogt

Associate Editor Klaus K.E. Neuendorf

Main Office: 910 State Office Building, 1400 SW Fifth Ave., Portland 97201, phone (503) 229-5580.

Baker City Field Office: 1831 First Street, Baker City 97814, phone (503) 523-3133. Howard C. Brooks, Resident Geologist.

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, \$6; 3 years, \$15. 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*, 910 State Office Building, 1400 SW 5th Ave., Portland, OR 97201. 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*, 910 State Office Building, 1400 SW 5th Ave., Portland, OR 97201.

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, a file copy on 5-in. diskette may be submitted in addition to the paper copies. Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be typed together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 6th ed., 1978.) 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

Bayocean peninsula, the sand spit at Tillamook Bay, projects 4 mi northward from Cape Meares. A dike along the bay was built to close a mile-long gap eroded during a storm in 1952. Article beginning on page 57 discusses archaeological finds from the bay area as possible evidence of periodic breaching of the spit in the past, not just by storms but by wave erosion from earthquake-related tsunamis or bay seicheing.

OIL AND GAS NEWS

Rules being finalized

Public hearings were held during April regarding the implementation of House Bill 2089 (1989 Legislature). These will provide for ground-water protection and surface reclamation when shallow exploratory holes, such as seismic shot holes, are drilled by the oil and gas industry in Oregon. Public hearings were also held during April on the revisions to administrative rules for oil and gas exploration and development in Oregon. Copies of these rules should be available during July. For details, contact Dan Wermiel at the Oregon Department of Geology and Mineral Industries (DOGAMI), phone (503)-229-5580.

Report on Tyee Basin oil, gas, and coal resources released

The first publication produced in the five-year Tyee Basin study project has been released by the Department (see description in the March issue of *Oregon Geology*, p. 36). The project was begun in mid-1988 and is funded by a consortium of public and private supporters. The Tyee Basin, an area of more than 4,000 mi² in the southern Oregon Coast Range, is underlain dominantly by Eocene sedimentary rocks.

Much of the information presented in the report consists of previously confidential research data and is made available here for the first time through the cooperation of several oil companies.

The report has been released as DOGAMI Open-File Report O-89-3 (price \$9) and is entitled *Geology and Oil, Gas, and Coal Resources, Southern Tyee Basin, Southern Coast Range, Oregon*. It was produced by A.R. and W.A. Niem of Oregon State University, with major contributions by E.M. Baldwin of the University of Oregon.

NWPA Field Symposium scheduled

The Northwest Petroleum Association has scheduled its 1990 Annual Field Symposium for September 30, October 1, 2, and 3, 1990, in Roseburg, Oregon. The symposium will include one day of talks relating to energy development, primarily oil and gas, in the Pacific Northwest. Two days of field trips will be held to observe the strata of the Tyee Basin and Coos Basin areas. For details, contact the NWPA, P.O. Box 6679, Portland, OR 97228-6679. □

Papers on industrial minerals published

Papers presented at the 25th Forum on the Geology of Industrial Minerals have been published by the Oregon Department of Geology and Mineral Industries (DOGAMI). The Forum was held in spring 1989 in Portland, Oregon, and was attended by about 120 industrial mineral specialists from all parts of the United States, Canada, and Great Britain.

The new publication is entitled *Industrial Rocks and Minerals of the Pacific Northwest. Proceedings of the 25th Forum on the Geology of Industrial Minerals, April 30 to May 2, 1989, Portland, Oregon*, and has been released as DOGAMI Special Paper 23.

In addition to the 16 technical papers presented at the Forum, the 100-page publication contains the chronology of the Forums that have been held annually since 1965 in 22 different states of the U.S. and in Toronto, Ontario, and a list of the participants at the 25th Forum.

Six of the technical papers present surveys of occurrences and production of various industrial minerals in the Pacific Northwest

(Continued on page 70, *Proceedings*)

Geothermal exploration in Oregon, 1989

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

INTRODUCTION

Geothermal exploration activity increased somewhat in 1989 relative to 1988. Drilling occurred on the flanks of Mount Mazama near Crater Lake National Park, at Santiam Pass, in the Alvord Desert, and in the Western Cascades. The amount of leased land and lease revenues declined sharply on federal lands. 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 1970-1989. Figure 2 shows the same information for geothermal prospect wells. Tables 1 and 2 list the Oregon Department of Geology and Mineral Industries (DOGAMI) permits for geothermal drilling that were active in 1989. Six new permits were issued, three for prospect holes and three for geothermal wells. Eight holes were drilled. Four shallow (< 152 m) temperature-gradient holes drilled by the U.S. Geological Survey (USGS) in the northern part of the Western Cascades had temperature gradients typical of background values for the area. A well drilled to a depth of 450 m in the Alvord Desert produced 1,211 liters per minute of 152 °C water in a 22-hour flow test (press release by Anadarko Petroleum Corporation). A temperature-gradient hole drilled by California Energy Company (CEC) near the east boundary of Crater Lake National Park reached a temperature of 129 °C at 1,068 m depth (Daily Journal of Commerce

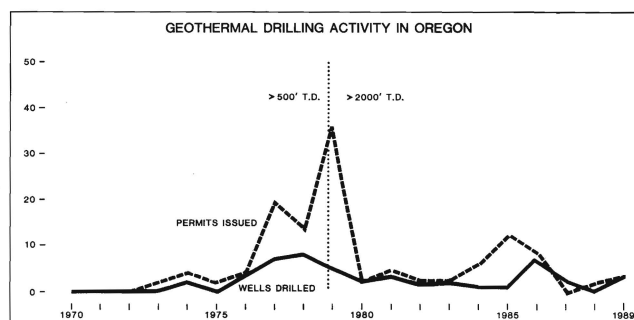


Figure 1. Geothermal well drilling in Oregon. Vertical line indicates time when definition of geothermal well was changed to a depth greater than 610 m.

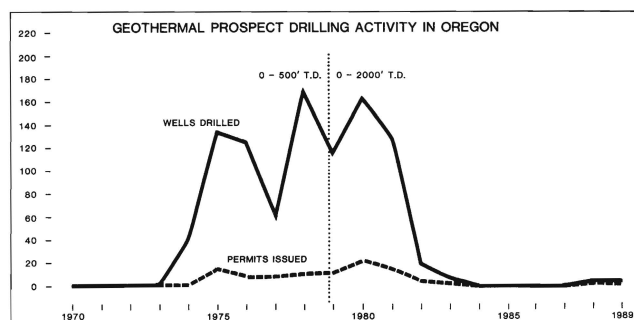


Figure 2. Geothermal prospect well drilling in Oregon. Vertical line indicates time when definition of prospect well was changed to a depth less than 610 m.

Table 1. Active permits for geothermal drilling in 1989

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	Suspended; confidential.
117	Calif. Energy Co. MZII-1 (deepening) 36-035-90015-80	SE¼ sec. 13 T. 32 S., R. 6 E. Klamath County	Suspended; confidential.
118	GEO* N-1 36-017-90013	SW¼ sec. 25 T. 22 S., R. 12 E. Deschutes County	Suspended; 1,387.
124	Thermal Power Co. CTGH-1 36-047-90002	SE¼ sec. 28 T. 8 S., R. 8 W. Marion County	Plugged; 1,463.
125	GEO* N-2 36-017-90018	SW¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Suspended; confidential.
126	GEO* N-3 36-017-90019	NE¼ sec. 24 T. 20 S., R. 12 E. Deschutes County	Suspended; 1,219.
131	GEO* N-4 36-017-90023	NE¼ sec. 35 T. 21 S., R. 13 E. Deschutes County	Suspended; confidential.
132	GEO* N-5 36-017-90024	NE¼ sec. 8 T. 22 S., R. 12 E. Deschutes County	Suspended; confidential.
135	GEO* NC88-29 36-017-90027	SE¼ sec. 29 T. 21 S., R. 12 E. Deschutes County	Canceled.
136	GEO* NC54-5 36-017-90028	NE¼ sec. 5 T. 22 S., R. 12 E. Deschutes County	Canceled.
137	DOGAMI Cache Creek No. 1 36-017-90029	NW¼ sec. 1 T. 14 S., R. 8 E. Deschutes County	Canceled.
138	GEO* NC54-5 36-017-90030	NE¼ sec. 5 T. 22 S., R. 12 E. Deschutes County	Permit; 3,048.
139	Oxbow Power Corp. 77-24 36-031-90001	SE¼ sec. 24 T. 13 S., R. 7½ E. Jefferson County	Suspended; 141.
140	Calif. Energy Co. MZI-9 36-035-90017	SW¼ sec. 9 T. 31 S., R. 7½ E. Klamath County	Canceled.
141	Calif. Energy Co. MZI-11 36-009-90018	SW¼ sec. 11 T. 31 S., R. 7½ E. Klamath County	Withdrawn by applicant.
142	Calif. Energy Co. MZI-11B 36-035-90019	SW¼ sec. 14 T. 31 S., R. 7½ E. Klamath County	Suspended; confidential.
143	Calif. Energy Co. CE-BH-4 36-017-90031	SW¼ sec. 27 T. 16 S., R. 9 E. Deschutes County	Permitted; 1,676.

* GEO-Newberry Crater, Inc.

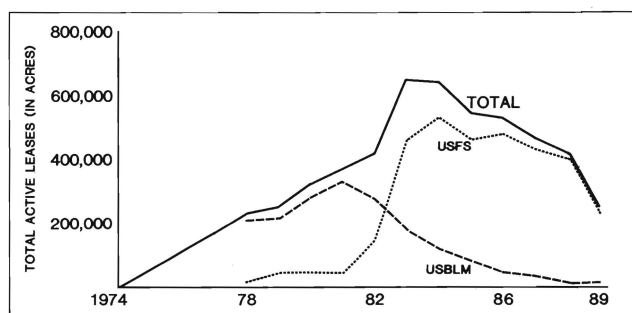


Figure 3. Active geothermal leases on federal lands in Oregon from the inception of leasing in 1974 through December 1989.

article, March 15, 1990). CEC also deepened a nearby hole, but the results are confidential. The Oxbow Power Corporation, working cooperatively with DOGAMI, rotary-drilled to 141 m near Santiam Pass. The Santiam Pass hole is scheduled to be diamond-cored to approximately 900 m in July of 1990.

LEASING

The consolidation of land holdings continued in 1989 as the total leased acreage of federal lands decreased by about 40 percent (Table 3; Figure 3). This decrease in leased lands was almost entirely caused by a decline in USDA Forest Service (USFS) leases (Table 3). U.S. Bureau of Land Management (USBLM) leases also suffered declines, but so little USBLM land is leased that it contributed little to the total. This decrease marks the sixth straight year of decline since the 1983 peak in total leased acreage.

Part of the reason for the steep decline in leased lands is a shift from leasing on the flanks of Newberry volcano to areas in the High Cascades. Lease applications for approximately 85,000 acres in the High Cascades, principally in the Bend highlands and Santiam Pass area, are currently being processed with the USFS (Robert Fujimoto, personal communication, 1990).

Figure 4 is a graph of the annual total monies received by the federal government from geothermal leasing in Oregon from 1974, when leasing was initiated, to the present. Included in the graph is income from filing fees, rental on competitive and non-competitive leases, and bonus bids. Income from geothermal leasing peaked in 1980 at \$1,701,189 and has declined steadily since then to its present level of about \$268,000.

KNOWN GEOTHERMAL RESOURCE AREA (KGRA) SALES

No KGRA lands were offered for bid in 1989. Some KGRA lands at Newberry volcano will probably be incorporated into a proposed geological monument (see section on regulatory actions).

Table 2. Active permits for geothermal prospect drilling in 1989 (holes less than 610 m)

Permit no.	Operator, well name	Location	Issue date; status
97	Anadarko Petroleum Well 25-22A	Alvord Desert area	Suspended; confidential.
98	USGS	Mount Hood National Forest, two sites	June 1989; drilled to 153 and 70 m.
99	USGS	Willamette National Forest, two sites	June 1989; drilled to 92 and 46 m.

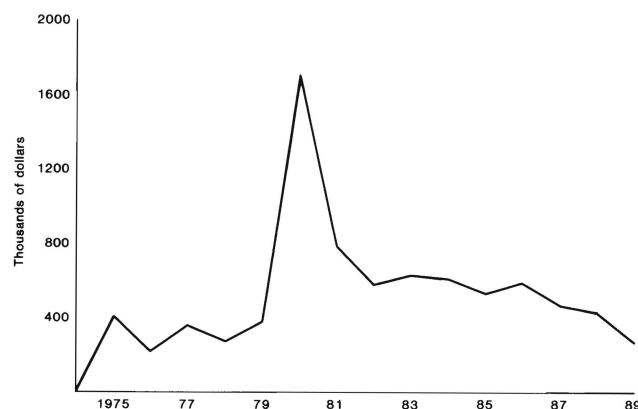


Figure 4. Federal income from geothermal leases in Oregon from the inception of leasing in 1974 through December 1989.

REGULATORY ACTIONS

USFS and USBLM officials met with industry and environmental groups in February 1989 to work out a preliminary boundary for the proposed Newberry Volcanoes National Monument. The area of the monument will reportedly encompass much of the land formerly classified as KGRA. Bills establishing the monument were submitted to the House (HR 3840) and Senate (S 1947) on November 21, 1989. These bills are under review at present.

DIRECT-USE PROJECTS

The direct use of relatively low-temperature geothermal fluids continued in 1989 at about the same level as over the last several years. Most of the activity is centered in Klamath Falls and Vale.

Ashland

Jackson Hot Springs in Ashland, Oregon, is still being operated as a resort.

Klamath Falls

The City continued to wrestle with the problem of defective piping installed in its district heating system. In 1989, the City completed engineering plans for the replacement of the defective pipe connections, and replacement should occur in the near future. Further expansion of the system is planned utilizing the Small Scale Energy Loan Program of the Oregon Department of Energy.

La Grande

The Hot Lake Recreational Vehicle Resort is utilizing 85 °C water from the Hot Lake artesian well to heat a pool and building. The company hopes to eventually use the resource to heat a fish-farming operation and to generate electricity.

Lakeview

In Lakeview, the binary-cycle electrical generating station set up several years ago remains idle. The 300-kilowatt (kw) unit had an output of 250 kw from 105 °C water in a November 18, 1982, test (Geo-Heat Center Quarterly Bulletin, 1982).

Paisley

The Paisley area has one of the best quality but least utilized low-temperature geothermal resources in the State. Thermal wells there reportedly have high flow rates (observations of Gerald L. Black, 1981) and temperatures as high as 111 °C at only 228 m (Oregon Department of Geology and Mineral Industries, 1982). A campground and recreational-vehicle park utilizes hot water for a pool, but no other uses are known.

Vale

In Vale, the successful Oregon Trail Mushroom Company, which commenced full-scale operations in 1986, continues to operate using water from a 107 °C aquifer for heating and cooling. Oregon Trail annually produces 2.3 million kilograms of mushrooms, which are marketed in Spokane, Seattle, Salt Lake City, and the Treasure Valley area in Idaho (Geo-Heat Center Quarterly Bulletin, 1987). Ag-Dryers, a grain-drying facility, also uses the resource.

USGS ACTIVITIES

1989 saw the publication by the U.S. Geological Survey (USGS) of 27 papers discussing the geological, geophysical, and tectonic setting of the Cascade Range, as part of the proceedings of a workshop held in December 1988 (Muffler and others, 1989b). Contributors included earth scientists from the USGS, universities, and the state geological surveys of Oregon and Washington. Many of these papers, as well as other contributions, are soon to be published in a special volume of the *Journal of Geophysical Research*. Pat Muffler and Marianne Guffanti are continuing their assessment of the geothermal potential of the Cascade Range (Muffler and Guffanti, 1989).

Also published in early 1989 was a small-scale (1:500,000) compilation map of the Cascade Range in Oregon, summarizing a decade of work by several contributors (Sherrod and Smith, 1989). In addition, full-color maps showing greater detail are now in press: (1) part of the Cascade Range between Three Sisters and Crater Lake (Sherrod, in preparation) and (2) west half of the Klamath Falls 1° x 2° quadrangle (Sherrod and Pickthorn, in preparation). Eleven new K-Ar age determinations for the Klamath Falls map will soon be published by *Isochron/West* (Pickthorn and Sherrod, in preparation).

Dal Stanley has integrated several east-west magnetotelluric-profile interpretations with regional seismic-refraction modeling (Stanley and others, 1989). This work better defines a high conductive (2 to 20 ohm-meters) zone that occurs at depths of 6 to 20 km and is largely confined within a mid-crustal layer with seismic velocity of 6.4 to 6.6 km/sec. The proposed model suggests that metamorphic zonation and fluids are responsible for superposition of these features.

Steve Ingebritsen and Bob Mariner continued water chemistry and hydrologic modeling of the Breitenbush Hot Springs and McKenzie Pass areas as part of a project to understand the circulation of meteoric and hydrothermal water in the Cascades (Ingebritsen and others, 1989a,b; Mariner and others, 1989).

Charlie Bacon's geologic map of Crater Lake is progressing. His studies will rigorously define the magmatic evolution and events leading to the caldera-forming climactic eruptions in Holocene time (Druitt and Bacon, 1989; Bacon, 1990). Field work included five dives with the portable submersible *Deep Rover*, during which samples were collected from the submerged parts of the caldera walls.

Keith Bargar and Terry Keith continued studies of hydrothermal-alteration mineralogy at Mount Hood, Newberry volcano, and the Clackamas River area. It is evident that low-temperature alteration (not much greater than 100 °C) is present to several kilometers depth in the Western Cascades, with no higher temperature minerals present. High-temperature mineralization is found only in areas adjacent to small plutons and hot springs.

Willie Scott coordinated a field trip in the Mount Bachelor-South Sister-Bend area for the Friends of the Pleistocene Fall 1989 Meeting (Scott and others, 1989). Trip leaders included Andrei Sarna-Wojcicki and Cynthia Gardner of the USGS and Edward Taylor and Brittain Hill of Oregon State University (OSU). Other Oregon Cascade field trips were conducted in association with the Santa Fe, New Mexico, meeting of the International Association of Volcanology and Chemistry of the Earth's Interior (Muffler and others, 1989a; Swanson and others, 1989).

The year 1989 also saw the beginning of a major investigation of Mount Hood, a volcano that heretofore was relatively unstudied despite its obvious hazard potential and proximity to the densely populated area of Portland and vicinity. This project is a cooperative effort between the Geologic and Water-Resources Divisions of the USGS and involves geologists Willie Scott, Tom Pierson, Bob Tilling, and Dave Sherrod. It will focus in part on downstream debris flows and floods, recent eruptive history, and geologic mapping and petrology of Mount Hood and vicinity. Field work by Dave Sherrod was concentrated mainly in the area southeast of Mount Hood, in an effort to finish three 15-minute quadrangles along the crest and east slopes of the range. Willie Scott is working mainly with the pyroclastic flows erupted from Mount Hood during the last 15,000 years.

BONNEVILLE POWER ADMINISTRATION

In its Draft 1990 Resource Program, Bonneville Power Administration (BPA) offered to purchase, in joint ventures with regional utilities, 10 MW of output from each of three geographically diverse geothermal pilot projects in the Northwest. The power contracts will include an option on the next 200 MW to be developed at each site. The main goal of the project is to determine the location, size, and cost of power at three of the largest, most promising sites in the region. Secondary goals are to encourage exploration, to build capability in regulators and developers, and to resolve land use issues that could impede development. If the projects proceed as scheduled, plants could start producing power as early as 1994.

BPA will also work with USFS, USBLM, and state energy offices to produce estimates of economic and land use impacts of geothermal development in areas where exploration is under way or imminent. Programs for public outreach and base-line environmental data collection are also being developed.

BPA has contracted with the Washington State Energy Office (WSEO) to produce a series of guides to the energy facility regulator maze in Idaho, Montana, Oregon, and Washington (WSEO is subcontracting appropriate parts of the project to the other three states). The guides will cover geothermal, hydroelectric, solar, wind, cogeneration, and biomass energy development. The geothermal guide is due in mid-1990 and will be followed by a workshop for developers, planners, and regulators in late 1990.

BPA is also participating, with the University of Hawaii and the Electric Power Research Institute, in a project aimed at improving our ability to use slim holes for reservoir assessment.

Table 3. Geothermal leases in Oregon in 1988

Types of leases	Numbers	Acres
Federal leases in effect:		
Noncompetitive, USFS	153	234,638.54
Noncompetitive, USBLM	1	622.79
KGRA, USFS	1	100.00
KGRA, USBLM	7	16,465.12
Total leases issued:		
Noncompetitive, USFS	357	685,805.79
Noncompetitive, USBLM	266	406,157.79
KGRA, USFS	8	11,924.61
KGRA, USBLM	62	118,307.85
Total leases relinquished:		
Noncompetitive, USFS	204	451,167.25
Noncompetitive, USBLM	265	405,535.00
KGRA, USFS	7	11,824.61
KGRA, USBLM	55	101,842.73
Lease applications pending	107	—

If the proposed technology proves to be feasible, then software will be developed to facilitate use. Expected completion date is mid-1991. A follow-on project might be a joint effort with a developer to test the technology in the Northwest.

DOGAMI APPLIED RESEARCH

DOGAMI formulated a scientific drilling program in 1987 (Priest and others, 1987a). Funding to support the program was found in 1989 from contributions of \$200,000 by the U.S. Department of Energy (USDOE) and \$100,000 by Oxbow Power Corporation (OPC). A hole was rotary-drilled and casing was set to 141 m in 1989 near Santiam Pass (Figures 5 and 6). The hole will be diamond-cored to about 900 m, and temperatures will be measured. It is hoped that the geologic and geophysical data from this hole will help to better understand the geologic history and regional heat flow near the axis of active volcanism in the Cascades. Those interested in participating in the project are encouraged to contact George R. Priest for further information.

In 1988, UNOCAL donated to DOGAMI core from four temperature-gradient holes that is currently available for use in research projects. The holes, drilled in the High Cascades near the South Sister and Mount Jefferson (Figure 5), reached depths ranging from 250 to 610 m. No temperature data from the holes are publicly available, but detailed lithologic logs are being produced as part of DOGAMI's scientific drilling program. The core is stored at Oregon State University, with representative samples available for inspection at DOGAMI.

An abstract in *EOS* (Priest and others, 1989) presents new isotopic age data for the UNOCAL holes. The paper shows that downward displacement on a complex graben structure in the Santiam Pass area is probably greater than or equal to 1.4 km. This amount of displacement is consistent with earlier interpretations of Taylor (1981). High permeability and geothermal fluids could occur in fractures and intergranular pore spaces associated with intra-graben faults and fill.

GEO-HEAT CENTER, OREGON INSTITUTE OF TECHNOLOGY

The Geo-Heat Center at the Oregon Institute of Technology (OIT) specializes in assisting in the development of low-temperature (< 90 °C) and moderate-temperature (90-150 °C) geothermal applications for direct use. The Center is under contract with USDOE to provide geothermal services to state and federal agencies who receive requests from engineering consultants, planners, and developers for development assistance on direct-use projects. The assistance can range from answering technical questions and simple consultations on methods, equipment, and applications to providing feasibility studies. The Geo-Heat Center has published over 70 such feasibility studies, which are available as examples. The project period is slated to run through the end of 1992.

The Geo-Heat Center continues to be involved in the evaluation of the Klamath Falls geothermal aquifer. Its staff plays an active role on the Klamath Falls Geothermal Advisory Committee and continues to publish the *Geo-Heat Center Quarterly Bulletin*, which has been in circulation since 1975.

ACTIVITIES OF OREGON WATER RESOURCES DEPARTMENT

The Oregon Water Resources Department (WRD) low-temperature geothermal program increased monitoring in the Klamath Falls area for aquifer pressure, temperature, and water-quality data in response to the City of Klamath Falls ordinance requiring injection of all geothermal effluent by July 1, 1990. WRD continues to monitor a light but persistent decline in the geothermal aquifer of about 0.3 m per year. Local officials feel that injection will halt this decline in the resource. WRD will continue to monitor to see whether any further steps are needed to stabilize the aquifer.

Jan Koehler recently joined WRD as a staff geologist, after having recently worked for the State Health Division drinking-water program. Jan brings a lot of water-quality control experience to the Department, which should be very useful in the geothermal program.

Senate Bill 237, passed in the last legislative session, requires WRD to develop rules that address several geothermal issues. The Department must adopt a "temperature below which low-temperature geothermal appropriations shall not be protected from thermal interference caused by ground-water appropriations for other purposes." The Department must also define terms such as "thermal interference" and "substantial thermal alterations."

Review of the statewide geothermal well and spring network continues, as WRD attempts to consolidate the net and assign monitoring efforts to the regional offices.

ACTIVITIES OF OREGON DEPARTMENT OF ENERGY

In 1989, the Oregon Department of Energy (ODOE) continued its research work, in cooperation with the Washington State Energy Office, on behalf of BPA. Results of both 1988 and 1989 work were presented to BPA in a July 1989 publication, "Innovative Design of Geothermal Generating Plants." ODOE put together additional case studies of two small independent power projects operating in Oregon. Neither was a geothermal plant, but the work provides BPA with insight necessary to eventually contract with a small geothermal developer.

ODOE provided comments on the Northwest Power Council (NPC) geothermal-issue paper and at a December NPC hearing presented testimony supporting geothermal energy development.

ODOE responds to public inquiries on geothermal energy development from the public, answering over 120 such inquiries in 1989. Since ODOE started keeping track of these inquiries in 1984, the yearly average is about 130 requests.

ODOE continues to certify geothermal tax credits for both homes and businesses in the state. In 1989, 70 residential tax credit applications were reviewed and 59 final certificates issued. The total number of geothermal residential tax credits issued from 1978 through 1989 is 596. Two geothermal business energy tax credit applications were reviewed in 1989. The total number of geothermal business energy tax credits issued from 1980 through 1989 is 40.

ODOE's geothermal specialist also attended the USDOE geothermal program review and the Geothermal Resource Council (GRC) Small (Geothermal) Power Plant meeting, taught a community college course session on geothermal energy at Central Oregon Community College, spoke at the USFS annual Lands and Minerals Conference, and published a paper on financial aspects of geothermal power plants for the annual GRC meeting.

RESEARCH BY OREGON STATE UNIVERSITY

Brittain Hill, a doctoral candidate at OSU, is continuing his work on Quaternary ash flows in the Bend area (Hill, 1985) and the silicic highland west of Bend. He will also be the field supervisor for scientific work on the scientific drill hole at Santiam Pass.

Jack Dymond and Robert Collier of the OSU College of Oceanography continued investigations at Crater Lake during the summer of 1989. Their objective is to determine whether or not hot springs exist on the floor of the lake. They contributed the following summary of their 1989 work.

Laboratory and surface-ship studies were extended during the summer of 1989 with deployment of the single-person submersible *Deep Rover*. The scientists used *Deep Rover* primarily to search out, observe, and sample thermal features in the bottom of the lake. In addition, they deployed in situ experiments to obtain time series measurements of flow rates, composition, and temperatures of the anomalous fluids found in certain parts of the lake. A total of 24 dives were carried out. Of these, five were funded by the

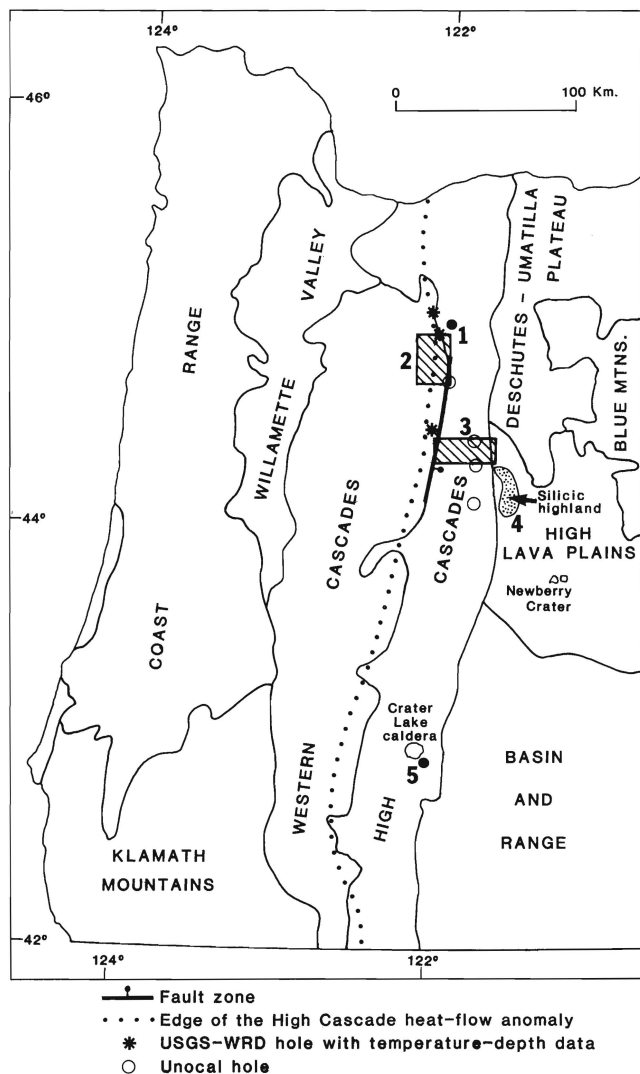


Figure 5. Physiographic provinces of western Oregon (after Dicken, 1950), showing major areas of geothermal activity discussed in text. 1. Location of Thermal Power drill hole CTGH-1. 2. Breitenbush study area. 3. Santiam Pass study area. 4. Silicic highland study area. 5. Location of CEC drill hole MZI-11A. Edge of High Cascade heat-flow anomaly after Black and others (1983).

USGS for observation and sampling of the lake's submarine geologic features. Four dives were funded by the National Geographic Society in order to carry out biological observations of moss and attached algae.

The submersible observations extended the areal coverage provided by the 1987 Remotely Operated Vehicle and the 1988 *Deep Rover* studies. These extended surveys located many additional colonies of chemoautotrophic bacteria. Most of the colonies were located within the southern basin that received major attention in 1988. However, a large area of bacteria coverage was located in the deep waters near Palisade Point. All the bacterial communities were associated with fluids 2-15 °C above the ambient temperatures that are found in the deep lake. These temperature anomalies are greater than those observed previously and, according to Dymond and Collier, exceed the USGS temperature criteria for geothermal waters.

One of the most surprising discoveries of the 1989 studies was the existence of pools of more saline water in the deep lake. These pools have dimensions ranging from a few centimeters to more than 10 m across. The pools are filled with fluids that are more than an order of magnitude more saline than normal lake waters. These waters have ^{222}Rn concentrations more than three orders of magnitude greater than background lake concentrations and have temperature anomalies of 2-6 °C above normal lake waters. Pools in the basin adjacent to the Palisades Point exhibited evidence of inlet and outlet channels in the sediments. These streamlike features may not presently be flowing, but erosional forms suggest that intermittent flow does occur. Bacterial communities of a variety of forms are associated with the pools, including both iron and sulfur oxidizers. The analytical program on the many aqueous and solid samples is currently underway.

RESEARCH BY WASHINGTON STATE UNIVERSITY

Richard Conrey is finishing up a four-year study of the Mount Jefferson area. He found that, for the last 2.5 Ma, about 200 km² of the area has been the site of andesitic to rhyodacitic volcanism (Conrey, 1988). He postulates that a granodiorite-tonalite batholith lies at shallow depths beneath the area.

MOUNT MAZAMA (CRATER LAKE) AREA

The reader is referred to Black and Priest (1988) for a detailed history of geothermal development issues at Mount Mazama prior to July 1988.

The National Park Service supported the research by Jack Dymond and Robert Collier of OSU mentioned above (section on Oregon State University).

In 1989, California Energy Company continued drilling on the two sites on the east side of the National Park that were discussed previously (section on drilling activity). In 1986, the MZI-IIA site (Table 1) had been drilled to 413 m, yielding a temperature of 107 °C at 405 m and a temperature gradient of 372 °C/km in the lowest 20 m of the hole (Priest and others, 1987b). Since the temperature at 1,068 m was only 129 °C, the high temperature gradient obviously did not persist at depth. These preliminary temperature data are, however, consistent with entry of thermal water in the upper part of the hole.

ACKNOWLEDGMENTS

This paper could not have been written without the cooperation of numerous individuals in government and industry. Jacki Clark of USBLM provided the federal leasing data. Bob Fujimoto of USFS provided much useful information on regulatory issues. Dennis Olmstead and Dan Werniel of DOGAMI furnished the data on drilling permits. Alex Sifford of ODOE and Susan Hartford of WRD provided information on their agencies' activities for the year. Gene Culver of OIT provided information on direct use projects around the state. David Sherrod and Terry Keith of USGS supplied accounts of USGS activities in Oregon. Jack Dymond and Bob Collier of Oregon State University provided the summary of their study of Crater Lake. George Darr of BPA contributed the section on his agency's activities.

REFERENCES CITED

- Bacon, C.R., 1990, Calc-alkaline, shoshonitic, and primitive tholeiitic lavas from monogenetic volcanoes near Crater Lake, Oregon: *Journal of Petrology*, v. 31, pt. 1, p. 135-166.
- Black, G.L., Blackwell, D.D., and Steele, J.L., 1983, Heat flow in the Oregon Cascades, in Priest, G.R., and Vogt, B.F., eds., *Geology and geothermal resources of the central Oregon Cascade Range*: Oregon Department of Geology and Mineral Industries Special Paper 15, p. 69-76.
- Black, G.L., and Priest, G.R., 1988, Geothermal exploration in Oregon, 1987: *Oregon Geology*, v. 50, no. 9/10, p. 107-116.
- Conrey, R.M., 1988, Mt. Jefferson area, Oregon High Cascade Range:

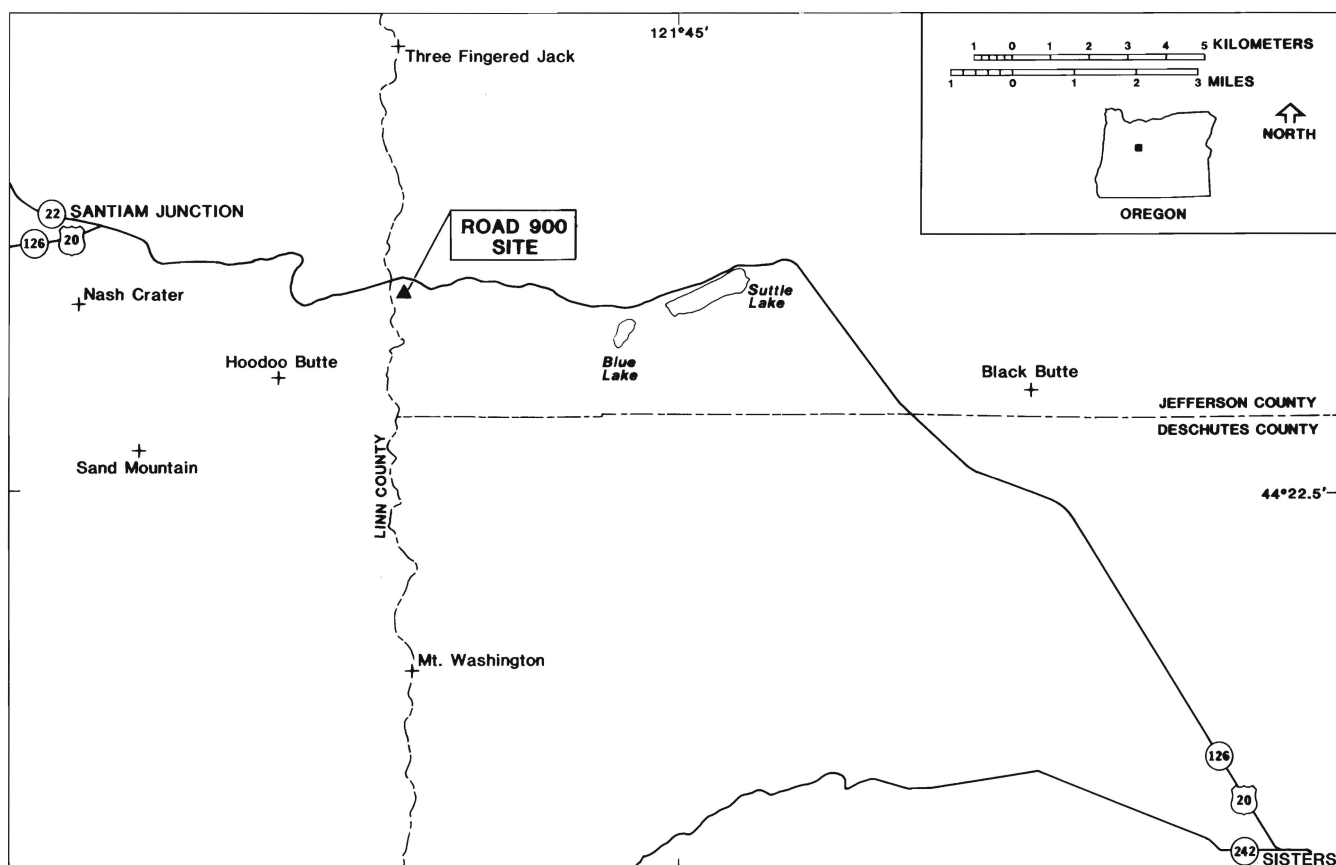


Figure 6. Location of scientific drill site near Santiam Pass, Oregon. Present depth, 141 m; target depth, 914 m.

- a long-lived locus of andesitic and dacitic volcanism and plutonism: Geological Society of America Abstracts with Programs, v. 20, p. A196.
- Dicken, S.N., 1950, Oregon geography: Eugene, Oreg., University of Oregon Cooperative Bookstore, 104 p.
- Druitt, T.H., and Bacon, C.R., 1989, Petrology of the zoned calc-alkaline magma chamber of Mount Mazama, Crater Lake, Oregon: Contributions to Mineralogy and Petrology, v. 101, p. 245-259.
- Geo-Heat Center Quarterly Bulletin, 1982, Low temperature geothermal power production in Lakeview, Oregon: Geo-Heat Center Quarterly Bulletin, v. 7, no. 3, p. 19-20.
- 1987, Geothermal pipeline: Geo-Heat Center Quarterly Bulletin, v. 10, no. 1, p. 17-19.
- Hill, B.E., 1985, Petrology of the Bend pumice and Tumalo tuff, a Pleistocene Cascade eruption involving magma mixing: Corvallis, Oreg., Oregon State University master's thesis, 101 p.
- Ingebritsen, S.E., Sherrod, D.R., and Mariner, R.H., 1989a, Heat flow and hydrothermal circulation in the Cascade Range, north-central Oregon, in Muffler, L.J.P., Weaver, C.S., and Blackwell, D.D., eds., Geological, geophysical, and tectonic setting of the Cascade Range: U.S. Geological Survey Open-File Report 89-178, p. 122-141.
- 1989b, Heat flow and hydrothermal circulation in the Cascade Range, north-central Oregon: Science, v. 243, p. 1458-1462.
- Mariner, R.H., Presser, T.S., Evans, W.C., and Pringle, M.K.W., 1989, Discharge rates of thermal fluids in the Cascade Range of Oregon and Washington and their relationship to the geologic environment, in Muffler, L.J.P., Weaver, C.S., and Blackwell, D.D., eds., Geological, geophysical, and tectonic setting of the Cascade Range: U.S. Geological Survey Open-File Report 89-178, p. 663-694.
- Muffler, L.J.P., Bacon, D.R., Christiansen, R.L., Clynne, M.A., Donnelly-Nolan, J.M., Miller, C.D., Sherrod, D.R., and Smith, J.G., 1989a, South Cascades arc volcanism, California and southern Oregon, in Chapin, C.E., and Zidek, J., eds., Field excursions to volcanic terranes in the western United States, volume II: Cascades and Intermountain West: New Mexico Bureau of Mines and Mineral Resources Memoir 47, p. 183-225.
- Muffler, L.J.P., and Guffanti, M., 1989, Integration of earth-science data sets to estimate undiscovered geothermal resources of the Cascade Range, in Muffler, L.J.P., Weaver, C.S., and Blackwell, D.D., eds., Geological, geophysical, and tectonic setting of the Cascade Range: U.S. Geological Survey Open-File Report 89-178, p. 695-703.
- Muffler, L.J.P., Weaver, C.S., and Blackwell, D.D., eds., 1989b, Geological, geophysical, and tectonic setting of the Cascade Range: U.S. Geological Survey Open-File Report 89-178, 706 p.
- Oregon Department of Geology and Mineral Industries (DOGAMI), 1982, Geothermal resources of Oregon, 1982: DOGAMI/National Oceanic and Atmospheric Administration (for USDOE), 1 sheet, map scale 1:500,000.
- Pickthorn, L.B.G., and Sherrod, D.R., in preparation, Potassium-argon ages from Klamath Falls area, south-central Oregon: Isochron/West.
- Priest, G.R., Bargar, K.E., Black, G.L., Blackwell, D.D., Couch, R.W., Collier, R., Duncan, R.A., Dymond, J., Evans, J., Goldstein, N., Haimson, B.C., Hughes, S., Iyer, M., Keith, T.E.C., Korosec, M.A., Laul, J.C., Levi, S., Mariner, R.H., Mooney, W.D., Rowley, J., Sherrod, D.R., Smith, M., Waibel, A., Weaver, C.S., Woller, N.M., and Wright, P.M., 1987a, Investigation of the thermal regime and geologic history of the Cascade volcanic arc: First phase of a program for scientific drilling in the Cascade Range: Oregon Department of Geology and Mineral Industries Open-File Report O-86-3, 120 p.
- Priest, G.R., Black, G.L., Mattinson, J.M., Damon, P.E., and Shafiquallah, M., 1989, Implications of new isotopic age data from drill holes in the Oregon Cascades [abs.]: EOS, v. 70, no. 43, p. 1299.
- Priest, G.R., Woller, N.M., Blackwell, D.D., and Gannett, M.W., 1987b, Geothermal exploration in Oregon, 1986: Oregon Geology, v. 49, no. 6, p. 67-73.
- Scott, W.E., Gardner, C.A., and Sarna-Wojcicki, A.M., eds., 1989, Guidebook for field trip to the Mount Bachelor-South Sister-Bend area, central Oregon High Cascades: U.S. Geological Survey Open-File Report 89-645, 66 p.

(Continued on page 66, Geothermal)

Paleoseismicity and the archaeological record: Areas of investigation on the northern Oregon coast

by John Woodward, archaeologist, Mount Hood Community College, 26000 SE Stark, Gresham, Oregon 97030; James White, consultant and shell expert, P.O. Box 795, Portland, Oregon 97207; and Ronald Cummings, archaeological technician, 11933 SE Foster Road, Portland, Oregon 97266.

INTRODUCTION

"Then everything got dark; no one could see anything. The men could not go fishing, women were unable to go root digging, nothing could be done. Very soon the water began to rise. Many small things were drowned, small people....That little muskrat came back. He carried that sun....Everywhere there was daylight again, and all the flood went down" (Jacobs and Jacobs, 1959, p. 83-84).

This quotation is from a Nehalem-Tillamook myth recorded in 1934 by anthropologist Elizabeth Jacobs. The storyteller was Clara Pearson, probably the last fluent speaker of the Nehalem language on the northern Oregon coast. According to Mrs. Pearson, this story with its catastrophic flooding belonged to the earliest time period of the Tillamook oral literature. Stories of the myth age were assigned to happenings long before the 19th century.

Although great flood myths are frequently encountered worldwide, can this Nehalem version have originated in an actual event that happened on the northern Oregon coast between 300 and 400 years ago? Recently, geological, dendrochronological, and archaeological evidence has been produced to support the theory that coastal areas of Oregon and Washington have experienced catastrophic earthquake-generated subsidence or tsunami flooding (known popularly as "tidal waves") or both at least twice in the last 1,000 years.

This theory has now been widely reported in both scientific and popular literature. Yeats (1989) writes, "The submergence of archaeological sites indicates that earthquakes affected Native American communities prior to the establishment of a culture that kept written records."

The earthquake-subsidence record evidence for the Oregon and Washington coasts first received widespread public interest following publication of a paper by B.F. Atwater in *Science* in 1987 (Atwater, 1987). Atwater presents the results of a geologic study of the Washington coast, showing that during the last 7,000 years intertidal mud has rapidly buried coastal marshes at least six times. Atwater writes, "Nothing other than rapid tectonic subsidence readily explains the burial of the peat layers." At Willapa Bay, a sand sheet extending 3 km inland and covering a marsh surface is attributed to an earthquake-generated tsunami.

Tsunamis, or seismic sea waves, can take several forms. Seismic sea waves are very low and long, with sea heights of less than 1 m. Moving as shallow-water waves, their velocity and coastal crest height vary greatly due to bottom contours, headland refraction, and other local variables. These multiply or reduce wave height and may result in either a huge cresting wave front or simply an unusually rapid rise in water level. Another variable of a tsunami's local effect on estuaries is the magnitude of the seiching, or shore-to-shore ("bathtub") wave action, that occurs in wave-disruptive bodies of water that are partially enclosed. Bascom (1980) writes, "A Pacific tsunami will usually succeed in exciting all the bays and harbors around its rim. Often these will oscillate for days." Tsunami-generated seiches can occur harmonically, with water-level changes in a bay happening every few minutes and exceeding in height the normal tidal fluctuations. Such events in shallow estuaries could result in significant bank erosion and mud deposition.

The source of the rapid subsidence and earthquake-generated tsunamis is likely to be a megathrust earthquake on the Cascadia Subduction Zone that extends less than 100 km off the coast of Washington and Oregon. Although there is no historic precedent, Heaton and Hartzell (1987) indicate that earthquakes of great magnitude might occur on the Cascadia Subduction Zone, generating

ground shaking lasting longer than two minutes and causing tsunamis of significant size. Subduction zone megathrust earthquakes in an analogous situation in Japan have generated local tsunami heights of greater than 6 m. A great subduction megathrust earthquake in Chile in 1960 generated local run-up heights exceeding 20 m.

At Netarts Bay (Figure 1) on the Oregon coast, Peterson and others (1988) have also shown the presence of rapidly buried marshes that they attribute to episodes of abrupt coastal subsidence. Twelve core sites in marsh lands of this bay showed several episodes of marsh burial in the last 3,300 years. Radiocarbon analysis indicates that the most recent events occurred less than 400 years before the present (B.P.). A date of A.D. 1580 $\pm$ 60 was obtained from the top of a marsh surface that is overlain by a sediment-capping layer associated with "catastrophic sheet floods over the subsided marsh system" (Peterson and others, 1988). In another, more recent paper, Darienzo and Peterson (1990) present additional data derived from sediment and diatom analyses that further support the presence of tectonic subsidence and tsunami deposition at Netarts Bay.

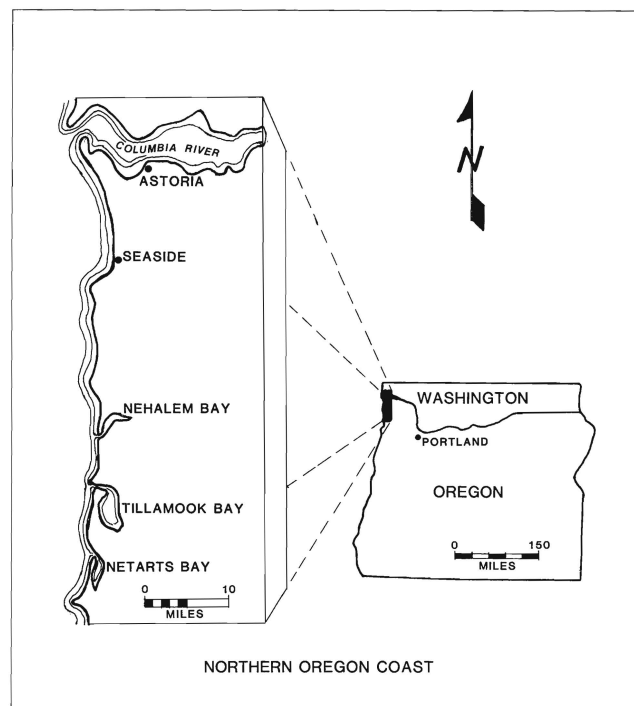


Figure 1. Map of the northern Oregon coast showing locations discussed in the text.

Grant and McLaren (1987) describe a similar buried marsh at the Salmon River estuary, approximately 40 km south of Netarts Bay, with evidence of a landward-directed surge of sandy water that deposited a thin layer of capping sand for at least 2 km along the Salmon River estuary. At Nehalem Bay, Grant found a marsh buried beneath sand and silt that she attributes to an episode of rapid subsidence.

Tree-ring data have also been examined for evidence of sudden coastal landform disruption. Carver and Burke (1987) have found disruptive growth rings in trees on the northern California coast dated at about 300 years B.P. The disruption is attributed to a landslide that could have been earthquake-generated. Dendrochronologist Yamaguchi and others (1989) report that cedar trees along a 60-mi span of the southern Washington coast died about the same time. Yamaguchi also is quoted in the *Oregonian* (Hill, 1989) as stating, "This is the first strong evidence that this subsidence event occurred synchronously up and down the coast." Yamaguchi attributes the death of the cedars to sudden submergence of the tree roots below high tide, with the tree rings indicating that this event occurred close to A.D. 1680.

Estuaries are highly sensitive environments that rapidly reflect subtle microenvironmental changes. This is especially true of those mollusks and fish most likely to be preserved in datable archaeological contexts. With the data from four coastal localities, we are attempting to appraise the archaeological evidence of sudden landform or sea-level changes on the northern Oregon coast as a contribution to the evaluation of earthquake hazards in Oregon.

NETARTS BAY

Netarts Bay has an estuary of 2,300 acres. It is protected behind a sand spit and has no large streams emptying into it. Its long-term stability is shown by the presence of every species of bay clam found in Oregon and, significantly, three that are not found in other Oregon estuaries. Edible shell fish that were found in Netarts Bay include the gaper (*Tresus capax*) and cockle (*Clinocardium nuttallii*). Both of these are easily obtainable in bay sand or sandy mud and were extensively dug and eaten by native peoples. Other less common but edible clams, the butter clam (*Saxidomus giganteus*) and the bent-nose clam (*Macoma nasuta*) are also found in Netarts Bay, where they occur close to the surface in gravelly or sandy mud (Oregon Department of Fish and Wildlife, 1982).

During late prehistoric times, a native village was established on Netarts sand spit, resulting in the deposition of an extensive shell midden (refuse pile) over 2 m deep in places (Archeological Site 35TI1).

The upper levels of the midden are composed of about 50 percent gapers and about 50 percent cockles. Other shellfish including butter clams were also observed but in small numbers. The occupation of this site continued into the historic period, with metallurgical analysis of copper alloy artifacts recovered from a late housepit indicating that the site was still in use during the late 1700's (Steele, written communication, 1985). Two radiocarbon dates of A.D. 1670±150 and A.D. 1800±150 were obtained from a late housepit in which copper artifacts and pre-19th century Chinese ceramics were also found.

This shell midden was excavated in the 1950's by Thomas Newman, who observed that the lowest 35 cm of midden deposits included masses of crushed shell, mammal bones, bone-woodworking tools, and cooking pits. A single radiocarbon date of A.D. 1400±150 was obtained from this lowest (i.e., oldest) midden level. Newman did not report any evidence of abandonment of the site or observe a clear break between the lowest midden and later deposits—which could be interpreted as the result of sudden landform changes—but he writes, "It is quite clear that occupation of this stratum did not take place under conditions existing today. Both sea level and water table must have been substantially lower to permit occupation" (Newman, 1959). He notes that, at the level of the lowest midden, these deposits were inundated by high tide all months of the year. He writes, "If highest tides and fresh-water table were lowered by 1 m, the site as it must have been during occupation would have been barely habitable....A 2-m drop in both sea level and fresh-water table would allow occupation at all times except under the severest conditions."

Thus, from Newman's comments it appears that the evidence

of the lowermost shell midden is suggestive of subsidence/sea-level change. However, alternative, nontectonic explanations can also be considered. Northwest coastal villages were often located very close to the upper limit of high tide, and food-processing and cooking activities typically took place on the beaches in front of domiciles. As a result of these practices, cultural materials including shellfish and fire-cracked rocks would likely accumulate where periodic tidal inundation occurred.

If abrupt subsidence did occur at Netarts Bay during the last 500 years and resulted in as great a vertical displacement as Newman's evidence suggests, it must be reconciled with the archaeological record of a continuing shellfish-gathering community at this location both before and after this event. A sudden drop in elevation of 1 m or more should have drastically affected the local mollusk harvest. Probably this elevation change also would have caused the rapid wave erosion of much of the sand spit protecting the relatively small and narrow estuary. Perhaps, because Netarts Bay does not have any significant watercourses emptying into it, the shellfish population of the estuary recovered from the effects of such disruption. This might not have been possible, however, without the sand spit surviving as a protective barrier, a condition that would be consistent with the archaeological evidence for Site 35TI1.

Nevertheless, more recently, Darienzo and Peterson (1990) presented strong, core-derived evidence that a tsunami-generated marsh burial and subsidence of at least 1.3-1.5 m occurred between 300 and 400 years B.P. This magnitude of sea-level change is close to Newman's estimate based on midden depth.

TILLAMOOK BAY

Tillamook Bay is 9 km north of Netarts Bay and is the second largest estuary (14,000 acres) on the Oregon coast. It has approximately seven times the surface area of Netarts Bay and periodically in prehistoric times was significantly larger than today. Five rivers and numerous streams and sloughs empty into the bay. In addition to shellfish, salmon returning to these streams provided an important food resource available to prehistoric inhabitants. The Wilson River site (Site 35TI2) is situated on a low cobble terrace at the point where the Wilson River formerly emptied into Tillamook Bay. Due to silting during the last 120 years, the bay is now about 4 km farther west. This estuary, like all other major Oregon coastal estuaries, has formed behind a protective sand spit that is highly vulnerable to storm action. The spit protecting Tillamook Bay has been breached by storms in historic times and is now protected by a breakwater. However, even if the sand spit did not exist, the Wilson River site would be partially protected from ocean waves by a headland (Pitcher Point) about 6 km to the northwest.

The Wilson River site was chosen for archaeological subsurface investigations in 1989 for several reasons: (1) shellfish remains were visible in the midden deposits and appeared to be interspaced with strata where shellfish were absent; (2) the depth of the site (over 2 m) indicated a long and probably continuous occupation; and (3) the site is situated on a major bay immediately north of Netarts Bay and would presumably have experienced the same marsh burial events documented at Netarts.

The extensive Wilson River site was originally excavated during the 1970's by relic collectors who destroyed approximately 80 percent of the cultural deposits. Fortunately, however, some information derived from these uncontrolled excavations was published by Sauter and Johnson (1974). The excavators noted that the composition of the midden deposits varied both in depth and proximity to the river. The latest occupation was found on high ground farthest away from the river where there were housepits surrounded by a shell midden. This portion of the site appeared to be late prehistoric and historic and was probably the location of the Tillamook Indian community that still existed there in 1852 (Vaughan, 1852). Sauter and Johnson reported that the shell midden associated with this late village included

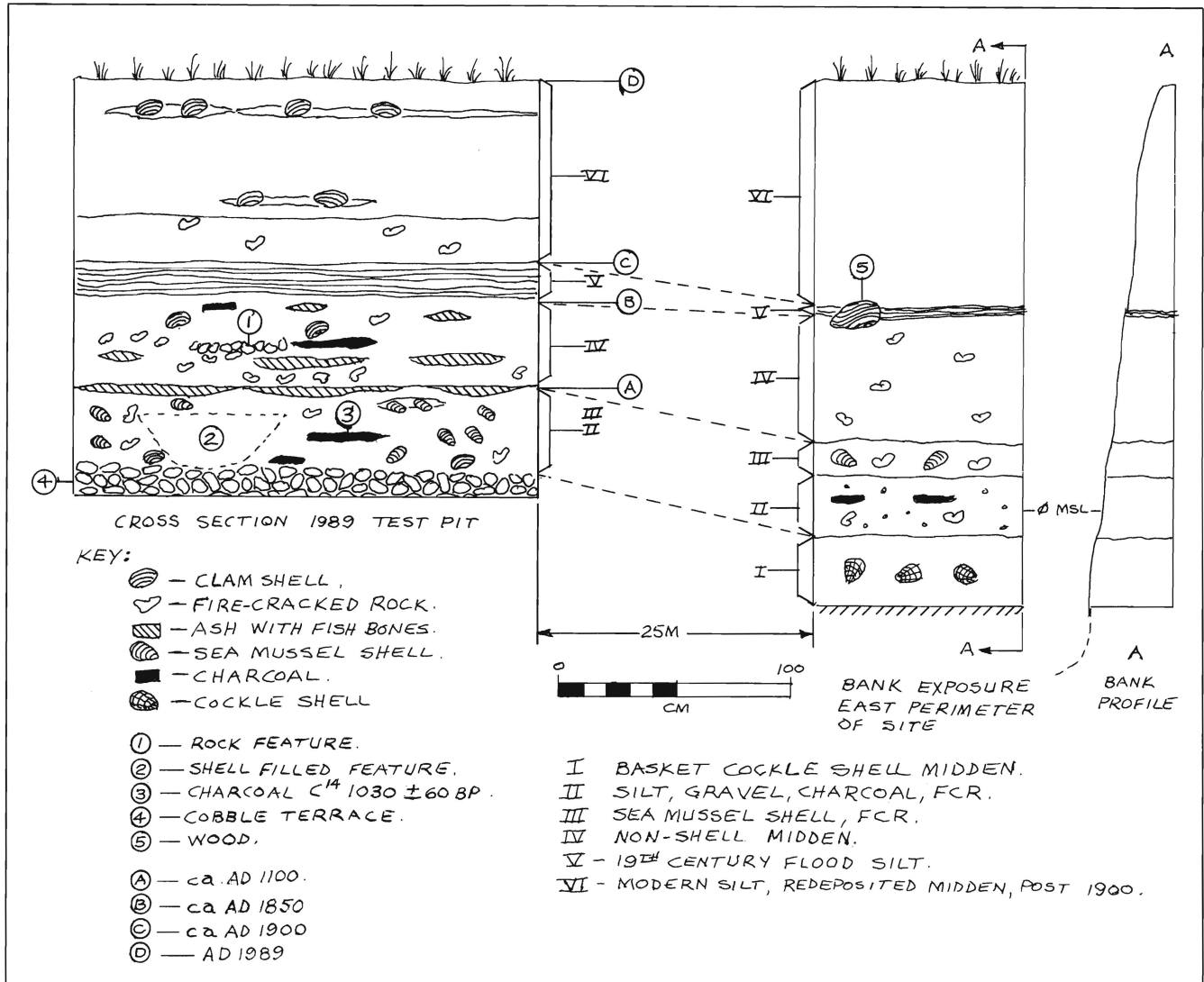


Figure 2. Stratigraphy of Wilson River Site 35TI2, Tillamook Bay. FCR = fire-cracked rock.

the mollusks generally found in Tillamook Bay as well as salmon bones. Artifacts reportedly associated with the occupation included whale bone clubs with carved zoomorphic designs, elk antler digging-stick handles, and awls and wedges made from bone. Beneath this shell midden, the authors reported a nonshell midden that was an "oily, charcoal-filled layer of midden which contained hundreds of bird bones and mammal bones of elk, deer, bear, beaver, sea otter, cougar...whale vertebrae." These deposits also included evidence of extensive flint knapping and the use of flaked-stone arrow points. The lowest midden and that closest to the river was observed to include a "lower shell midden" with a higher frequency of bone tools, harpoons, fishhooks, and toggle points than other areas. Although Sauter and Johnson did not attempt to correlate the differences observed in the site's midden, they noted the resource shifts indicated by the midden composition and suggested that time lapses may have occurred between occupations.

Archaeological investigations were conducted at the Wilson River site in August 1989 by college archaeology classes from Tillamook Bay Community College and Mount Hood Community College. A trench 24 m long and 2 m wide was excavated by arbitrary 10-cm levels to the base of the midden. The area chosen was a narrow strip of previously unexcavated soil located parallel to the Wilson River and adjacent to the area dug over by relic

collectors. At the time of the excavation, river bank erosion was exposing cultural material to about the summer high-water line.

In early 1990, bank erosion approximately 25 m upstream from the trench location exposed an in situ shell midden located at an even lower level. In this lower shell midden, a 31-cm-thick stratum of large basket cockles, *Clinocardium nuttallii* (Conrad), was visible (Figure 2). The shells were largely intact and cemented together in a compact silt matrix. This stratum is interpreted as representing the result of dumping the shells into a relatively quiet water rather than as representing a living surface, so that, as such, the exposure does not necessarily indicate subsidence. The cockles indicate the presence of an estuarine environment nearby, although it may not have been identical with that found today. The cockle stratum is overlain by a 23-cm-thick layer of nonshell midden containing fire-cracked rocks and charcoal in a mud matrix containing gravel. No break in the site's use was observed between the cockle stratum and this layer; however, mollusks appear to be entirely absent in the higher layer.

Above the nonshell midden is a 14-cm-thick, dense, blue-appearing deposit of highly fragmented shells of the sea mussel, *Mytilus californianus* (Conrad). This mussel is found in dense beds on intertidal rocks along the open coast and occasionally in sheltered waters north to British Columbia. It has been widely used as a

food source by many cultures. Exclusive presence of the sea mussel would indicate an open-coast environment, with a rocky shoreline (either cobbles or larger base rock). Mussels would survive on cobbles that would not be rolled around by the surf in storms, which are largely from the southwest in the Tillamook area. It should be noted that if the Tillamook sand spit were not present, the Wilson River mouth would largely be sheltered by the projection of Pitcher Point, which would block the sea directly west of the river mouth.

We interpret from the presence of sea mussels in such great quantities and the absence of estuarine forms that the Tillamook (Bayocean) sand spit did not exist at the time this level was deposited. During recorded times, the sand spit at Bayocean was developed and deteriorated. At one time, it was breached by the ocean, and if it had not been for the intervention of the U.S. Army Corps of Engineers, Tillamook Bay might have again reverted to open-coast environment. This was not the result of a catastrophic geological incident but a shifting of natural forces.

The mussel stratum abruptly ends and is overlain by a 57-cm-thick nonshell midden. Only minute unidentifiable particles of shells that were possibly the result of vertical transport were observed. We suspect they were moved to this level through activities of earthworms, rodents, trampling, and other human and natural activities and originated in lower and/or higher levels. This

stratum is capped by a series of flood-deposited silts including tree limbs, historic artifacts, and redeposited midden.

Observations of other bank exposures at this site show a white, chalky-appearing shell midden occurring as lenses at the top of the nonshell midden and composed of bay clams and some gastropods. The predominant clam that was observed is the basket cockle, *Clinocardium nuttallii* (Conrad). Also found are the butter clam, *Saxidomus giganteus* (Deshayes); the gaper clam, *Tresus capax* (Gould); and the frilled dogwinkle snail, *Nucella lamellosa* (Gmelin). These are currently found in Tillamook Bay. The basket cockle is abundant and was a major portion of the commercial clam harvest of Tillamook Bay during the first part of this century.

The shell finds in the upper level are consistent with the present estuarine environment of Tillamook Bay. This late, upper shell midden appears to correlate with the uppermost cultural material excavated by Sauter and Johnson and associated with the late prehistoric/historic Tillamook Indian use of the site. By the inception of this occupation, the Tillamook Bay estuary was fully established with the mollusk types found historically near this location.

It is significant to note that there are substantial layers of deposits without shells separating the bay clam/sea mussel/bay clam stratum. A time period would be expected before reestablishment of species in a radically changed ecology. The layers without shells appear to represent such periods of reestablishment. It would also be expected that the bay clam to sea mussel interspace would be less, as sea mussels could be readily introduced from adjoining open coast, while bay clams would need transport of a substantial distance from other estuaries.

The excavated trench provided additional data concerning the site's stratigraphy. The lowest cultural materials consisting of a 30-cm-thick shell midden correspond to the mussel shell layer observed in the bank. In the trench, however, this deposit rests directly on a cobble terrace. Above the mussel shell midden is a nonshell midden 45 cm thick that is capped by flood silts dated to the late 19th century. Above this are mixed and redeposited materials including lenses of shells from the late midden. A radiocarbon date of A.D. 920±60 was obtained from charcoal recovered from the mussel shell midden.

If we consider the above-mentioned data alone, it would appear that a sand spit formed Tillamook Bay around 920 A.D., and the sea mussels were not able to survive. We can further speculate that the nonshell midden represents the subsequent time period in which clam veliger larvae finally arrived in the new bay in sufficient numbers to develop a reproducing population. This would have taken an extended period, for the predominant ocean flow past Tillamook Bay is southerly. To the north, Nehalem Bay, which is a relatively new estuary, contains different species. The Necanicum estuary was probably gone by 920 A.D. Larvae of the butter clam would probably have traveled from somewhere north of the Columbia River, and the gaper clams may have been introduced from Netarts. Cockle clams can survive in the open ocean, where they are possibly washed from estuaries. Such survival populations might have been the first to become introduced, which could account for the abundance of cockles.

Significantly, both the eroded bank exposures and trench stratigraphy do not show a hiatus in the site's occupation despite what appear to be abrupt shifts in resource procurement. The excavations showed that the mussel shell midden and the nonshell midden above it contain very similar artifact assemblages with a high percentage of bone and antler woodworking tools. Both contain significant numbers of sea and land mammal bones and salmon bones. Elk and deer were the dominant mammals hunted during both periods. Duck bones were found only in the nonshell midden, a finding consistent with the assumption that this was the time of bay development. Arrow points from the mussel shell midden are represented by only four examples; three of these are lanceolate; one has a contracting stem. Arrow points from the

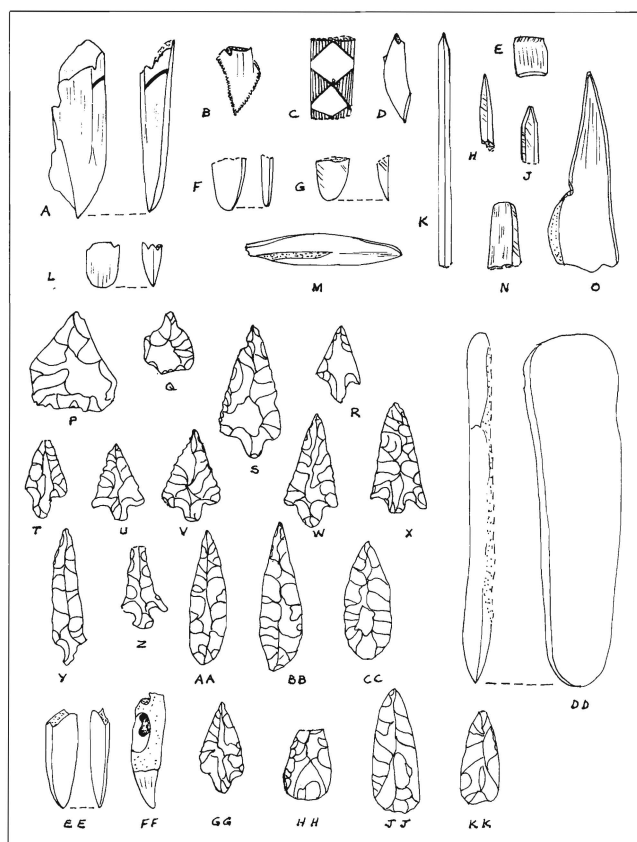


Figure 3. Artifacts of the Wilson River site, A-DD of a nonshell midden, EE-KK of a mussel shell midden. A = bone wedge fragment; B = shark's tooth; C = decorated antler; D = beaver tooth chisel; E = bone bead fragment; F, G, L = tips of antler wedges; H, J = bone points; K = bone needle; M = bone harpoon part; N = base of bone harpoon; O = bone awl; P = flaked stone knife; Q = flaked stone perforator; R-Z = flaked stemmed arrow points; AA-CC = flaked leaf-shaped points; DD = stone adze; EE = tip of bone wedge; FF = sea mammal tooth pendant; GG = flaked stone arrowpoint; HH-KK = flaked lanceolate point. Length of DD is 11.5 cm.

nonsell midden are more numerous and include both stemmed and leaf-shaped forms (Figure 3). The largest number of arrow points are stemmed forms recovered from the mixed upper deposits, where they were redeposited during the 20th century by leveling and filling of the site.

The midden deposits at the Wilson River site appear to show very significant environmental changes in Tillamook Bay over at least the last 1,000 years. These changes resulted in shifts in the availability of shellfish obtained within the catchment area of the site's inhabitants. Such shifts were apparently not viewed by the prehistoric inhabitants as sufficiently disruptive to bring about abandonment or relocation of the site. Also, they do not necessarily indicate abrupt subsidence at this location. (The inundated materials might be interpreted as the result of prehistoric trash disposal into the Wilson River rather than as changes in sea level.)

Yet, while there is no direct support for earthquake-generated catastrophic change at this locality, the abrupt disappearance in shellfish utilization can be interpreted as indicating that the rapid habitat change resulted from the periodic building and breaching of the sand spit protecting Tillamook Bay. That breaching and disappearing of the sand spit could have been caused by wave erosion from tsunamis and/or bay seiching.

NEHALEM BAY

With a surface area of 4,100 acres, Nehalem Bay is Oregon's fifth largest estuary (Figure 4). This estuary is unusual in that it does not contain the major beds of native shellfish found farther south. The only abundant clam is the softshell, *Mya arenaria* (Linne), found in tidal flats common along the northern and eastern edge of the bay. Although originally thought to have been introduced, its wide range suggests that it may be native. Unlike the other clams found in the estuaries, it has the ability to withstand significant changes

in salinity (White, 1976). Because it can survive in low salinity, it is found as far up the Nehalem River as the town of Nehalem. This clam might survive geological changes that would eliminate an estuary or an environment of a very limited estuary. However, its absence in the Nehalem middens suggests that it was recently introduced or was scarce in prehistoric times.

Near the mouth of the Nehalem estuary, we find a relative abundance of native littleneck clams (*Protothaca staminea*). Although this clam prefers a high salinity and is also found in sheltered coves along the open coast, its limited presence in Nehalem Bay would be consistent with a relatively new or re-established estuary. These clams occur in Nehalem middens with a scattered and limited distribution. Gapers, butterclams, and cockles also occur in Nehalem middens in small numbers, where they are intermingled with barnacles, ocean mussels, limpets, and sea snails. This suggests that they are not a nearby resource but were transported to Nehalem Bay through trade or infrequent visits to adjoining waters. In fact, Nehalem Bay, unlike Oregon's other major estuaries, lacks identified shell middens despite the presence of numerous late prehistoric house sites and a significant native population during the early historic period, probably because of the fragile nature of the protecting sand spit. This sand spit many have broken down at intervals sufficiently frequent to prevent the development of those conditions favorable to clam beds.

The oldest documented archaeological site of the group of sites at Nehalem Bay (Site 35TI4) is fully inundated and consists of a layer of fire-cracked rock overlain by a 35-cm-thick stratum of silt (Figure 5). The upper 10 cm of the silt include waterlogged organic materials containing leaves of willow, *Salix* sp., and red alder, *Alnus rubra*. Also present is moss (*Sphagnum* sp.), a cone of red cedar (*Thica plicata*), and numerous seeds of Sitka spruce (*Picea sitchensis*). Wood fragments and small logs also occur at the top of the silt and include Douglas fir (*Pseudotsuga menziesii*). These plants are found around Nehalem Bay at forested wetland margins located at present no closer than 0.9 km from this site. Fragments of a waterlogged twinned mat woven from Douglas fir root were found at the top of the silt. A portion of the mat has been radiocarbon dated to 380±60 years B.P., with a calibrated range of A.D. 1410-1635 (Woodward, 1986). This date is consistent with the radiocarbon date of 370±60 years B.P., with a calibration range of A.D. 1431-1660, obtained from the top of a buried marsh at Netarts (Peterson and others, 1988). The silt layer is interpreted as having formed in a sheltered tidal marsh that developed behind a prehistoric sand spit. Sand dunes bordering this marsh stabilized and were invaded by a dense growth of Sitka spruce, willows, red alder, and shrubs, creating a spruce swamp/tidal channel habitat. Leaves and other vegetation fell, were washed directly into a body of quiet shallow water, and there covered with silt. This phase ended abruptly between 300 and 400 years ago

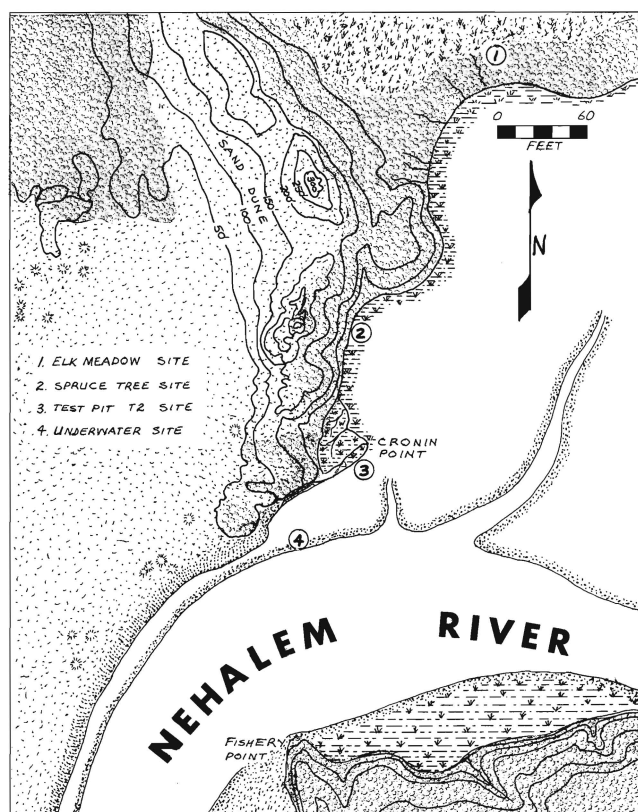


Figure 4. Nehalem Bay redrawn from 1875 map (U.S. Coast Survey Chart, 1875), showing sites discussed in text.

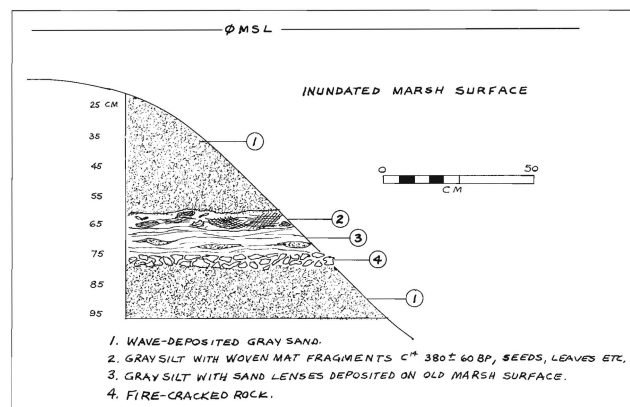


Figure 5. Underwater site, Nehalem Bay. MSL = Mean Sea Level.

with the disappearance of the sand spit and burial of the spruce swamp with wave-transported sand. This was a potentially catastrophic event for any prehistoric community at this location. More recently, channel shifts have cut into the deposits and exposed the edge of the site.

A portion of Nehalem Bay Site 35TI4 is on Cronin Point, which is shown as a tidal marsh in an 1875 geodetic survey of the bay (U.S. Coast Survey Chart, 1875) (Figure 4). At present, a portion of the southern edge of this marsh is experiencing seasonal tidal bank erosion, but other areas are being invaded by wave-deposited alluvium including both sand and cultural material eroded from the bank. These processes occur primarily during the fall and winter. During the spring and summer, silt tends to cover the site, which is largely stabilized by the growth of grasses.

Archaeological testing of this site in 1980 consisted of the excavation of four 1-m by 2-m test pits that were excavated to the summer low-tide water table. Stratigraphic profiles of two of these test pits are shown in Figures 6 and 7. They show evidence of repeated burial of marsh surfaces by wave-deposited sediments. The most recent episode of this process began during the late 19th century and is continuing today. Materials currently moving across the site include a partially sorted deposit consisting primarily of sand, lithic rubble, and mixed cultural materials of all ages. The first author has observed materials, including fist-sized rocks and recent debris, to have been transported at least a meter to the north-northeast by a single intense storm. In 1980, experiments conducted near the site showed that modern ceramic fragments between 1 cm and 5 cm in diameter were transported by incoming tidal action between 2 and 3 m a year in this direction, even without intense storm-tidal action. This rate suggests that much of the fire-cracked rock and artifacts observed at this site originated 200-300 years B.P. and were originally in situ about 550 m southwest of Cronin Point. The rate of littoral transport would, of course, be much more rapid if the Nehalem sand spit did not exist and the location were an open beach. Experiments cited in Bascom (1980) show that some of 600 radioactive pebbles tracked during an experiment on the east coast of England were moved as much as a mile from their original location.

The pattern of frequent episodic marsh burial at Cronin Point during late prehistoric and historic times makes the identification of possible tsunamis difficult because their effects are not easily differentiated from local effects of intense wave action generated by Pacific storms.

At the Spruce Tree site of 35TI4, in situ cultural material occurs beneath a sand dune (Figure 8). At the time this site was occupied, a Sitka spruce swamp existed at this locality,

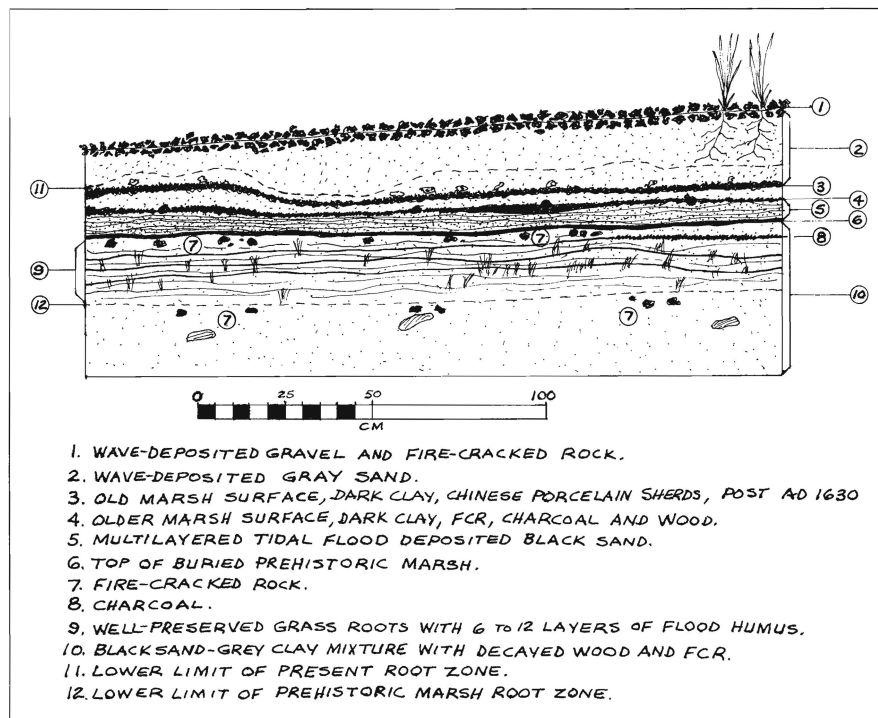


Figure 6. Cronin Point stratigraphy, West Wall Test Pit T2P1, Site 35TI4, Nehalem Bay.

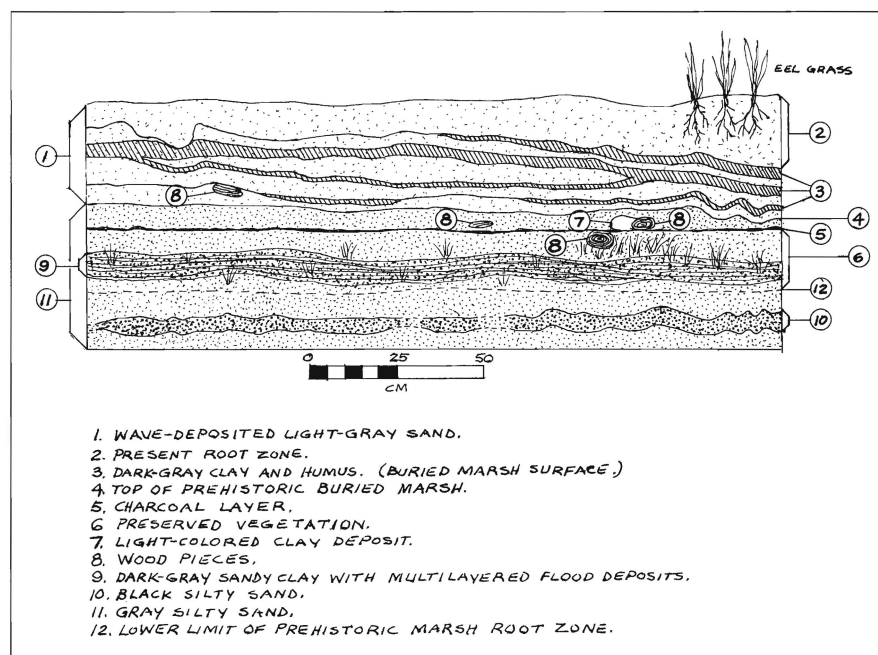


Figure 7. Nehalem Bay stratigraphy, West Wall Test Pit T2P2, Site 35TI4.

which is now marked by partially inundated roots of these trees. Fire-cracked rock and artifacts occur here on the present marsh surface. A radiocarbon date of 260 ± 40 years B.P. with a calibration of A.D. 1490-1670 has been obtained from charcoal associated with cultural materials (Woodward, 1986).

In 1989, the first author conducted test excavations at the Elk Meadow site of 35TI4

(Figure 9). This site is at the same elevation as the Spruce Tree site on the edge of a sand terrace that extends above sea level at least 2 km north. This site also has inundated spruce tree roots and is shown as forested on the Nehalem Bay survey of 1875. Since 1875, this forest has been replaced by a tidal marsh that has moved north at least 35 m since the site was occupied. The archaeolog-

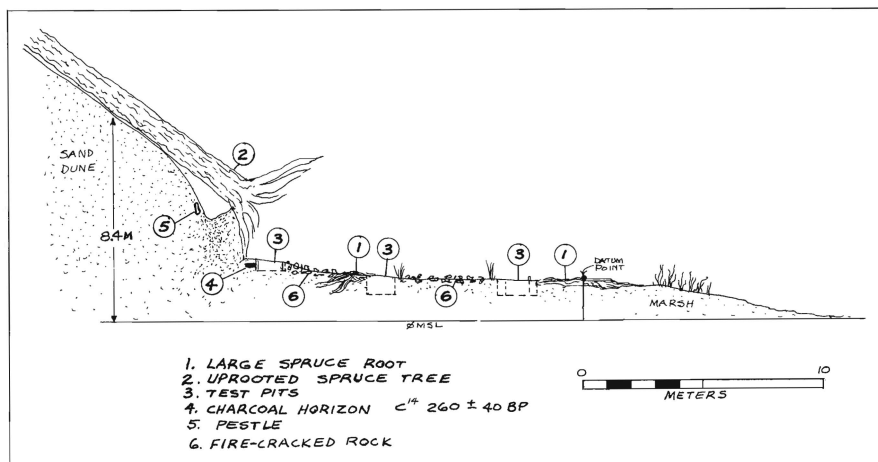


Figure 8. Spruce Tree site, Nehalem Bay.

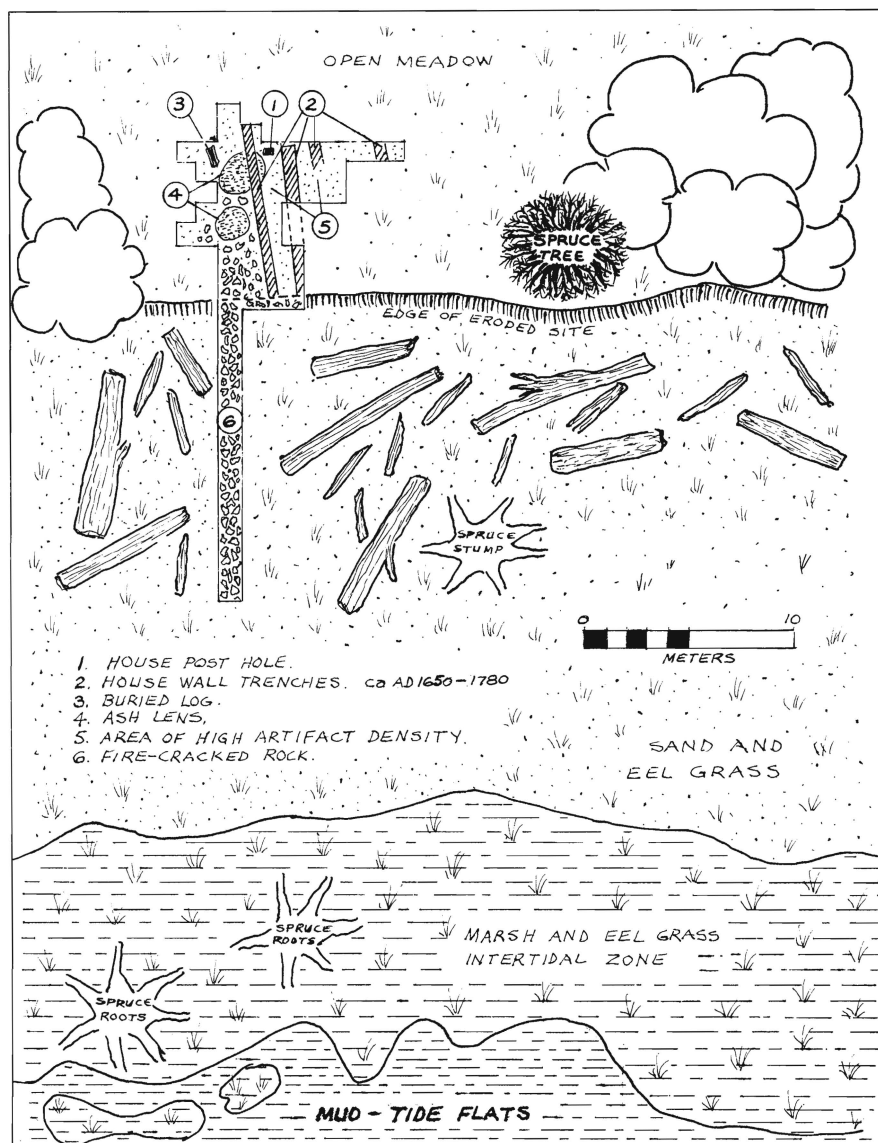


Figure 9. Elk Meadow site, Nehalem Bay.

ical excavations show that a plank(?) house at least 8.5 m long had been constructed fully above ground on the sand sheet. Evidence of food preparation includes a large amount of fire-cracked rock and small fragments of mammal and fish bones. The only bone large enough for identification was identified as from a Roosevelt elk (*Cervus roosevelti*). It is significant that shellfish are entirely absent.

The lithic artifacts recovered from the site include two pestles, eight small arrow points, a stone knife, and 25 hide scrapers (Figures 10, 11, and 12). Beeswax, Chinese ceramics, and iron, lead, and bronze artifacts that were found on the house floor are attributed to a shipwreck (or more) on the Nehalem sand spit (Figures 13 and 14). Absent are glass beads, rolled copper ornaments, or other artifacts associated with the early historic period. This house site, with its primary emphasis on hunting, fishing, cooking, and hide preparation, is dated to ca. A.D. 1650-1780.

The tidal archaeological sites around the Nehalem estuary show that rapid habitat and land-form changes have been ongoing since at least ca. 400 years B.P. Many of these are probably cyclic and associated with the position of the Nehalem River channel and the form of the Nehalem sand spit. At one earlier dated site, however, fully inundated cultural materials were found in association with a wetland pond/Sitka spruce swamp rapidly buried by a massive sand sheet. This burial may be interpreted as evidence of seismic-generated subsidence, a tsunami, or both. Such events would probably have brought about wave erosion of any protecting sand spit and would have exposed Nehalem Bay directly to ocean waves. One result of this could have been the formation of the beach-sand terrace on which the Spruce Tree and Elk Meadow sites are situated.

Geodetic survey maps and photographs made between 1868 (U.S. Coast Survey Chart, 1868) and 1940 show the Nehalem sand spit as a low, narrow, wind-deflated surface almost entirely devoid of vegetation. During the 19th century, the wrecks of possibly two ships were periodically visible on the spit following episodes of wind erosion. The last recorded time that a wreck was visible was 1926. Between 1890 and 1916, one wreck with exposed ribs, a keel, and teak-wood decking was partially stripped of its wood, which was then locally used to make furniture and souvenir walking canes. In 1989, the Quaternary Isotope Laboratory of the University of Washington obtained a radiocarbon date of A.D. 1638±21 (M. Stuiver, personal communication, 1989) from one of these Asian teak-wood (*Tectona grandis*) canes that had been in museum storage. With the age calibration of Stuiver, two age ranges were obtained: A.D. 1517-1593 and A.D. 1620-1639. The Quaternary Isotope Laboratory has also recorded a date of A.D. 1640±20 (M. Stuiver, personal communication, 1990) from a ship's pulley that was made

of an Asian wood (*Calophyllum* sp.) (Figure 15). Calibration of this date is A.D. 1519-1589 or A.D. 1622-1639. The pulley was found in 1896 on or near the teak-wood wreck.

The presence of shipwreck debris on the Nehalem spit indicates

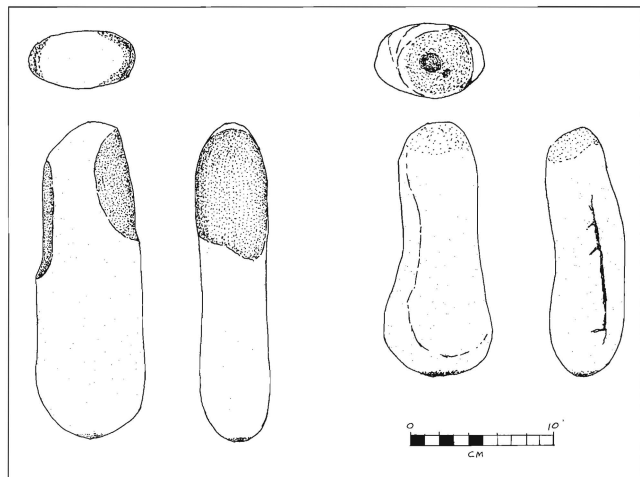


Figure 10. Stone artifacts, Elk Meadow site.

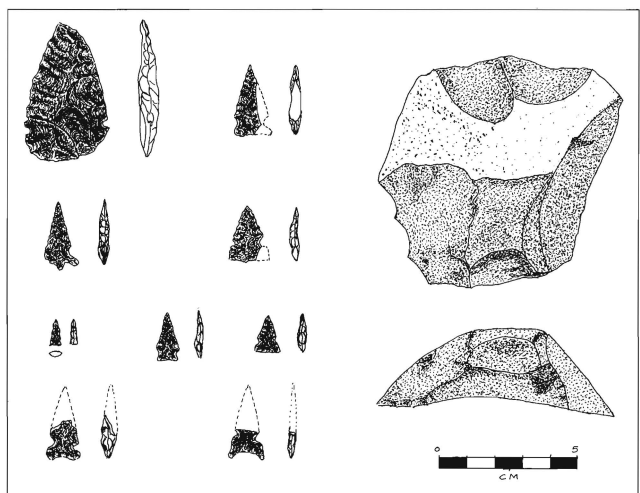


Figure 11. Flaked stone artifacts, Elk Meadow site.

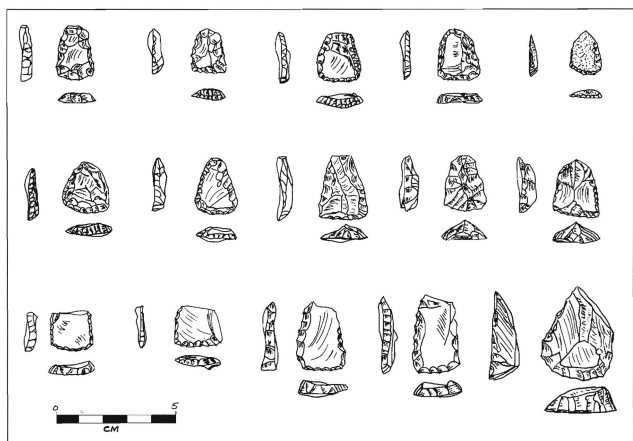


Figure 12. Hide scrapers, Elk Meadow site.

that the present spit has been in place in some form since at least the early 17th century. The teak-wood wreck lay on its side and is at present buried beneath about 3 m of wind-blown sand. This suggests that at the time of the wrecks, the spit assumed a far lower, more barlike configuration than it now has.

SEASIDE

At Seaside, Clatsop County, a three-site cluster situated on an old beach terrace was excavated by amateur archaeologists in the 1970's (Phebus and Drucker, 1979). Although a complete report is not available, some data concerning these shell middens have been published.

Radiocarbon dates show that the earliest occupation was established on a cobble terrace by at least 600 B.C. This culture, in addition to fishing and the hunting of land and sea mammals, collected bay clams (described as *Schizothaerus nuttallii*, *Saxidomus giganteus*, and *Protothaca staminea*), cockles (*Cardium* sp.), and sea mussels (*Mytilus californianus*). The likely source of the bay shellfish was the now-filled Necanicum estuary.

The site's stable occupation continued with no observed changes in midden composition until site abandonment about 185 B.C. Brief reoccupation is indicated about A.D. 200. A second period of intensive use of the locality occurred between A.D. 245 and 915. The shell middens from this second period lack the estuary shellfish but instead are composed primarily of sea mussels. Sea snails, barnacles, and

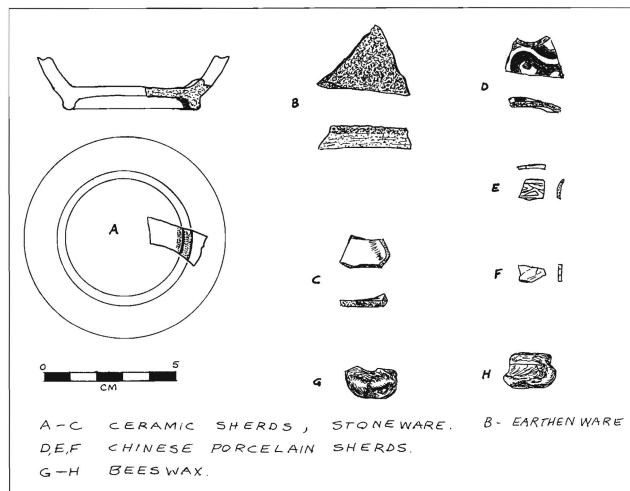


Figure 13. Ceramic and beeswax artifacts, Elk Meadow site.

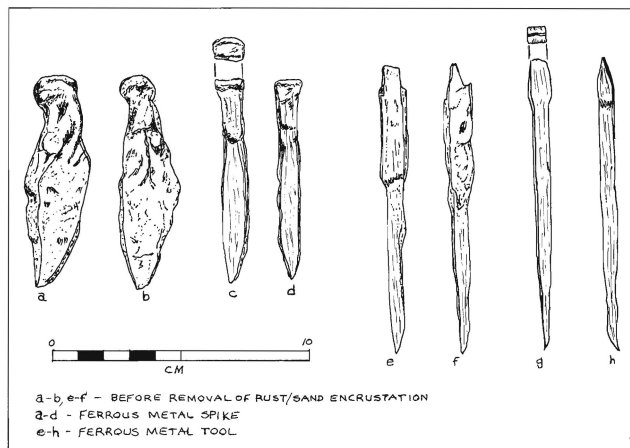


Figure 14. Iron artifacts, Elk Meadow site.

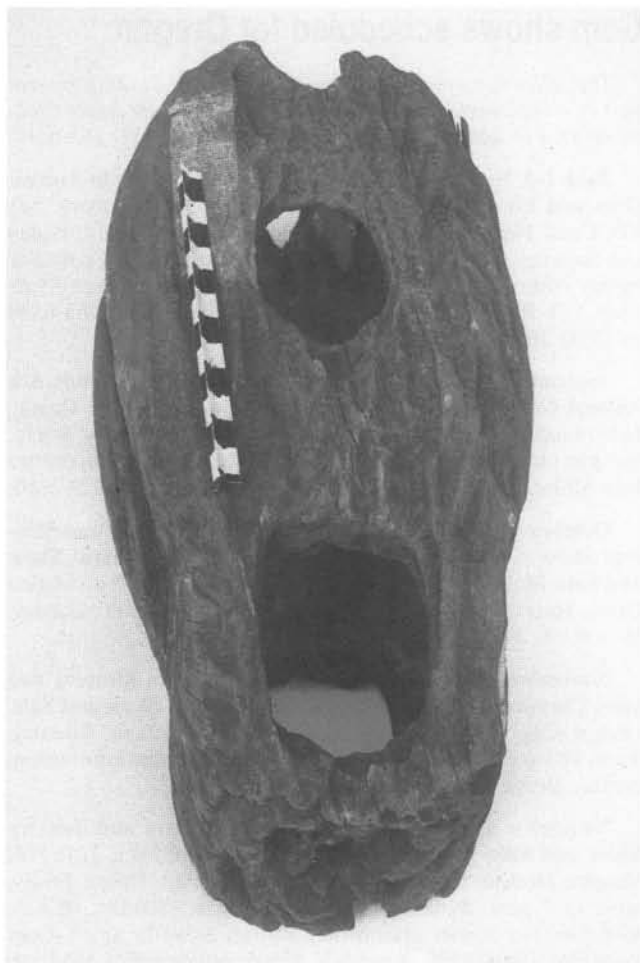


Figure 15. Ship's pulley from prehistoric shipwreck on Nehalem sand spit. Photo courtesy of Wayne Jensen, Jr.

razor clams were also observed, indicating that, at this time, the Necanicum estuary no longer was extant, and an open-beach environment existed similar to that found at Seaside today.

Although artifacts from both the bay-clam and the mussel-collecting cultures exhibit similar bone and stone tool types, there are enough significant differences in house form, artistic expression, and woodworking technology to indicate that the littoral mussel collectors may not have been the direct descendants of the earlier bay clam collectors. There is archaeological evidence that a population replacement occurred between A.D. 200 and 300 and was directly linked to a relatively rapid change in the Necanicum estuary and loss of its major shellfish resources. Phebus and Drucker (1979) conclude that "...the Seaside area, north of Tillamook Head, has undergone some dramatic topographical alterations that must have certainly required some serious economic adjustment on the part of the native population."

CONCLUSIONS

Archaeological sites located near four present or prehistoric estuaries on the northern Oregon coast show evidence of land-form/habitat changes associated with sand-spit stability during the last 2,000 years. Shellfish utilization by prehistoric inhabitants is an important indicator of estuary change that may be the result of rapid subsidence, tsunamis, or intense-storm waves. At Netarts, Tillamook, and Nehalem Bays, we find inundated archaeological materials that suggest sea-level changes resulting from subsidence. However, prehistoric human occupation at Netarts and Tillamook

Bays appears to have continued without being affected by catastrophic events. One of the archaeological sites on Nehalem Bay shows an episode of rapid microenvironmental changes and sand burial attributed to a tsunami, subsidence, or both. The result of this episode, which likely occurred between 300 and 400 years B.P., may have been catastrophic for any inhabitants of the site.

ACKNOWLEDGMENTS

We wish to express our special appreciation to Sharon Woodward for her assistance with excavation supervision, artifact drawing, and typing of this report. Barbara McCorkle also helped with artifact analysis and drawing, and Wayne Jensen of the Tillamook Pioneer Museum provided important support for archaeological research in Tillamook Bay. C. Dale Snow kindly took time to review the report, and Steve Cragg located funds for radiocarbon dating. Susan Foster and Jack Foster of Mount Hood Community College assisted in identification of faunal remains.

REFERENCES

- Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: *Science*, v. 236, p. 942-944.
- Bascom, W., 1980, *Waves and beaches*: New York, Doubleday, Anchor Press, 366 p.
- Carver, G.A., and Burke, R.M., 1987, Late Holocene paleoseismicity of the southern end of the Cascadia subduction zone [abs.]: *EOS*, v. 68, no. 44, p. 1240.
- Dariento, M.E., and Peterson, C.D., 1990, Episodic tectonic subsidence of late Holocene salt marshes, northern Oregon central Cascadia margin [abs.]: *Tectonics*, v. 9, no. 1, p. 1-22.
- Grant, W.C., and McLaren, D.D., 1987, Evidence for Holocene subduction earthquakes along the northern Oregon coast [abs.]: *EOS*, v. 68, no. 44, p. 1239.
- Heaton, T.H., and Hartzell, S.H., 1987, Earthquake hazards on the Cascadia Subduction Zone: *Science*, v. 236, p. 162-168.
- Hill, R., 1989, NW coast tree rings hold clues to quakes: *The Oregonian*, December 14, 1989, p. 61, 63.
- Jacobs, E.D., and Jacobs, M., 1959, *Nehalem Bay tales*: Eugene, Oreg., University of Oregon Monographs, Studies in Anthropology, 216 p.
- Newman, T., 1959, *Tillamook prehistory and its relation to the Northwest coast culture area*: Eugene, Oreg., University of Oregon doctoral dissertation, 118 p.
- Oregon Department of Fish and Wildlife, 1982, *Oregon's captivating clams*: Corvallis, Oreg., Oregon State University Extension Service, Sea Grant Publication 28, 10 p.
- Peterson, C.D., Dariento, M.E., and Parker, M., 1988, Coastal neotectonic field trip guide for Netarts Bay, Oregon: *Oregon Geology*, v. 50, no. 9/10, p. 99-106.
- Phebus, G.E., and Drucker, R., 1979, *Archaeological investigations at Seaside, Oregon*: Seaside, Oreg., Seaside Museum and Historical Society, n. pag.
- Sauter, J., and Johnson, B., 1974, *Tillamook Indians of the Oregon coast*: Portland, Oreg., Binford and Mort, 196 p.
- Steele, H., 1986, *Nonferrous objects from 35T11 metallurgical and metallographic comparisons*: Unpublished manuscript, available from Harvey Steele, P.O. Box 13293, Portland, OR 97213.
- U.S. Coast Survey Chart, 1868, *Oregon Historical Society Manuscript 775*: Portland, Oreg., Oregon Historical Society Library.
- 1875, *Oregon Historical Society Manuscript 782*: Portland, Oreg., Oregon Historical Society Library.
- Vaughan, W., 1852, *An early history of Tillamook, 1851-1852*: Tillamook, Oreg., Tillamook County Pioneer Museum manuscript.
- White, J., 1976, *Seashells of the Pacific Northwest*: Portland, Oreg., Binford and Mort, 127 p.
- Woodward, J.A., 1986, Prehistoric shipwrecks on the Oregon coast? Archaeological evidence, in Ames, K., ed., *Oregon Archaeologists Association, Third Annual Symposium, Portland, Oreg., 1985, Proceedings*: Albany, Oreg., Social Science Department, Linn-Benton Community College, p. 219-264.
- Yamaguchi, D.K., Woodhouse, C.A., and Reid, M.S., 1989, Tree-ring evidence for synchronous rapid submergence of the southwestern Washington coast 300 years B.P. [abs.]: *EOS*, v. 70, no. 43, p. 1332.
- Yeats, R., 1989, Current assessment of earthquake hazard in Oregon: *Oregon Geology*, v. 51, no. 5, p. 90-91. □

Number of significant earthquakes down in 1989

Although the magnitude 7.1 Loma Prieta earthquake that struck the Santa Cruz Mountains of California on October 17, 1989, made the United States particularly earthquake sensitive, the world actually had slightly fewer significant earthquakes during 1989 than the average for the past two decades.

Earthquakes are defined as "significant" if they register a magnitude of at least 6.5 or, with a lesser magnitude, cause casualties or considerable damage.

The average number of significant earthquakes per year has been about 60 since record-keeping began in the early 1970's. The 55 significant earthquakes reported during 1989 were also six fewer than the total for the previous year.

In addition, the 526 persons believed to have died in consequence of earthquakes around the globe in 1989 were significantly fewer than the 28,000 or more believed to have perished in earthquakes in 1988. The number is also well below the average of 10,000 deaths per year from earthquakes.

The most deadly earthquake of 1989 was a magnitude 5.3 tremor that shook the Tajik region of the Soviet Union on January 22, triggering landslides that buried several villages and killed an estimated 274 persons.

The second most deadly seismic event was a magnitude 5.7 earthquake in Iran on August 1 that is believed to have killed at least 90 people and injured 15, when their villages were struck by earthquake-induced landslides.

The strongest tremor and the only "great" earthquake (magnitude of 8.0 or larger) recorded was an 8.3-magnitude earthquake on May 23 in the South Pacific near the Macquarie Islands, about midway between Australia and Antarctica. The island region is sparsely populated, and there were no reports of injuries or damage.

The Loma Prieta earthquake in California caused 62 deaths, injuries to more than 3,500 people, and property damage estimated at \$5.6 billion. Five others of the world's significant earthquakes occurred in the United States or nearby waters. Only one of these, an August 8 tremor of magnitude 5.3 near Los Gatos, California, caused a death, when a young man became disoriented and jumped from a second-story balcony. The others occurred in Hawaii (June 26, magnitude 6.2), west Los Angeles (January 19, magnitude 5.2), southern Alaska (September 4, magnitude 6.9), and the Andreanof Islands of the Aleutians (October 7, magnitude 6.7).

Among the earthquake reports worldwide for 1989, a few items are particularly noteworthy: The People's Republic of China had five significant earthquakes that caused 37 deaths and considerable damage. At least 30 people were killed when a magnitude 5.9 tremor hit northern Algeria on April 15. Australia, which normally does not experience many damaging earthquakes, recorded at least 11 deaths and considerable damage when a magnitude 5.5 tremor hit Newcastle, near the southeastern coast on December 27. Japan, which recorded only one significant earthquake in 1988, experienced five significant tremors during 1989. All the earthquakes were centered east and south of the island of Honshu. One person was killed in a magnitude 5.5 tremor on February 19.

—U.S. Geological Survey news release

Notice to OSU geology graduates

We were asked by the Department of Geosciences of Oregon State University to publish the following notice:

To all Oregon State University Geology alums. If you have never received a Biennial Report, or if your address is wrong on the last report you have received, or if you know of someone who should be on the alum list, please send a current address to Therese Belden, Department of Geosciences, Oregon State University, Wilkinson Hall 102, Corvallis, OR 97331-5506, or call her at (503) 737-1238. □

Gem shows scheduled for Oregon

The following news of upcoming gem shows in Oregon were part of a list compiled by Kay Myers, Oregon Coast Agate Club, Newport. For additional information, call her at (503) 265-6330.

June 1-3, Newport: Oregon Coast Agate Club, 26th Annual Gem and Mineral Show. Oregon National Guard Armory, 541 SW Coast Highway 101. Dealers (no tailgating). Hours: Friday and Saturday, 10 a.m. to 6 p.m.; Sunday, 10 a.m. to 5 p.m. For further information, contact Ethel Baldie, c/o Oregon Coast Agate Club, P.O. Box 293, Newport, OR 97365, phone (503) 265-6330 or (503) 265-6334.

September 1-3, Canby: Willamette Valley Rockhounds, 8th Annual Gem, Mineral, and Jewelry Show. Clackamas County Fairgrounds, Highway 99E. Hours: Saturday and Sunday, 9 a.m. to 6 p.m.; Monday, 9 a.m. to 4 p.m. For further information, contact Jean Miller, Box 136, Molalla, OR 97038, phone (503) 829-2680.

October 19-21, Portland: Portland Regional Gem and Mineral Show Association, 10th Annual Gem and Mineral Show and Sale. Multnomah County Exposition Center, off I-5 on Marine Drive. Hours: Friday and Saturday, 10 a.m. to 7 p.m.; Sunday, 10 a.m. to 5 p.m.

November 10-11, Oregon City: Clackamette Mineral and Gem Corporation, 27th Annual Rock and Gem Show and Sale. Oregon City High School, 11th and Jackson. Hours: Saturday, 9 a.m. to 8 p.m.; Sunday, 10 a.m. to 5 p.m. For further information, contact Bernie Schultz, phone (503) 656-3347.

November 16-18, Portland: Gem Faire Gem and Jewelry Show and Sale. Montgomery Park Exhibition Center, 2701 NW Vaughn. Dealers' inquiries invited (no tailgating). Hours: Friday, noon to 7 p.m.; Saturday, 10 a.m. to 7 p.m.; Sunday, 10 a.m. to 6 p.m. For further information, contact Steve E. Small, Gem Faire, Inc., Box 3296, Reno NV 89505, phone (702) 356-0516 or (503) 265-6330. □

(Geothermal, continued from page 56)

- Sherrod, D.R., in preparation, Geologic map of a part of the Cascade Range between latitudes 43°-44°N, central Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map I-1891 (with pamphlet), scale 1:125,000.
- Sherrod, D.R., and Pickthorn, L.B.G., in preparation, Geologic map of west half of Klamath Falls 1° by 2° quadrangle, south-central Oregon: U.S. Geological Survey Miscellaneous Investigations Series Map, scale 1:250,000.
- Sherrod, D.R., and Smith, J.G., 1989, Preliminary map of upper Eocene to Holocene volcanic and related rocks of the Cascade Range, Oregon: U.S. Geological Survey Open-File Report 89-14, 20 p., 1 map, scale 1:500,000.
- Stanley, W.D., Fuis, G.S., and Mooney, W.D., 1989, Details of crustal structure in the Cascade Range and surrounding regions from seismic and magnetotelluric data, in Muffler, L.J.P., Weaver, C.S., and Blackwell, D.D., eds., Geological, geophysical, and tectonic setting of the Cascade Range: U.S. Geological Survey Open-File Report 89-178, p. 31-73.
- Swanson, D.A., Cameron, K.A., Evarts, R.C., Pringle, P.T., and Vance, J.A., 1989, Cenozoic volcanism in the Cascade Range and Columbia Plateau, southern Washington and northernmost Oregon, in Chapin, C.E., and Zidek, J., eds., Field excursions to volcanic terranes in the western United States, volume II: Cascades and Intermountain West: New Mexico Bureau of Mines and Mineral Resources Memoir 47, p. 1-50.
- Taylor, E.M., 1981, Central High Cascade roadside geology, Bend, Sisters, McKenzie Pass, and Santiam Pass, Oregon, in Johnston, D.A., and Donnelly-Nolan, J., eds., Guides to some volcanic terranes in Washington, Idaho, Oregon, and northern California: U.S. Geological Survey Circular 838, p. 55-58. □

The case of the counterclockwise river

by John Eliot Allen, Emeritus Professor of Geology, Portland State University, Portland, Oregon 97207-0751

INTRODUCTION

A tiny creek appears just east of Cochran, a former Southern Pacific Railroad station located at the summit elevation of 1,808 ft in a little-known pass through the northern Coast Range of Oregon. For 6 mi, the creek flows east to the town of Timber, where the valley widens and the creek, gathering water from several tributaries, meanders north for almost 10 mi across narrow flood plains and then turns northeast for 4 mi to Vernonia.

Within slightly incised meanders through a narrower valley, the creek continues from Vernonia north-northeast for 5 mi, then north-northwest for 5 mi, and northwest 4 mi to the town of Mist. There it takes a 6-mi arc to the west and southwest to arrive at Birkenfeld, where it begins a generally southwest-trending and deeply incised meandering course for 25 mi to the mouth of the Salmonberry River, a stream that completes the oval, since only 14 mi upstream to the east, the headwaters of one of its tributaries begin just south of Cochran, within a mile of where our river began!

This is the peculiar 65-mi-long counterclockwise loop made by the Nehalem River around the heart of the northern Coast Range before it turns west-southwest for the last 15 mi through deeply incised meanders to Nehalem Bay and the Pacific Ocean. The width of the Coast Range between Forest Grove and Tillamook Bay is less than 40 mi; the Nehalem River valley is more than 90 mi long.

DISCUSSION

The purpose of this essay is to develop multiple hypotheses, one of which might account for this apparently anomalous course of the Nehalem River, a minor geomorphic puzzle that has intrigued me for more than 40 years, ever since the publication of the first geologic map of the area (Warren and others, 1945). Old-fashioned armchair geomorphic analysis, "reading the contours" of topographic maps, which I have sometimes indulged in since my retirement (Allen, 1975, 1989a,b) can occasionally furnish valuable insights into the geologic history of an area.

I have heard that the course of the Nehalem River caught the attention of interpreters scanning satellite images, looking for "astroblesmes," structures produced by the impact of large meteorites or comets. Although this hypothesis (no. 1) can be quickly discarded, another hypothesis (no. 2) is suggested by similar drainage patterns that can form within giant calderas produced by great volcanic explosions.

Structural uplift or doming, as in the Black Hills of South Dakota, is a third more likely explanation (no. 3); its implications will be explored later. Still another hypothesis (no. 4) suggests that the Miocene Nehalem River, originally flowing east into the Columbia, was diverted north and then west by flows of Yakima Basalt filling the ancestral Columbia River valley.

Geographic factors that can be investigated during a study of these hypotheses are statistics on relative rainfall, length and gra-

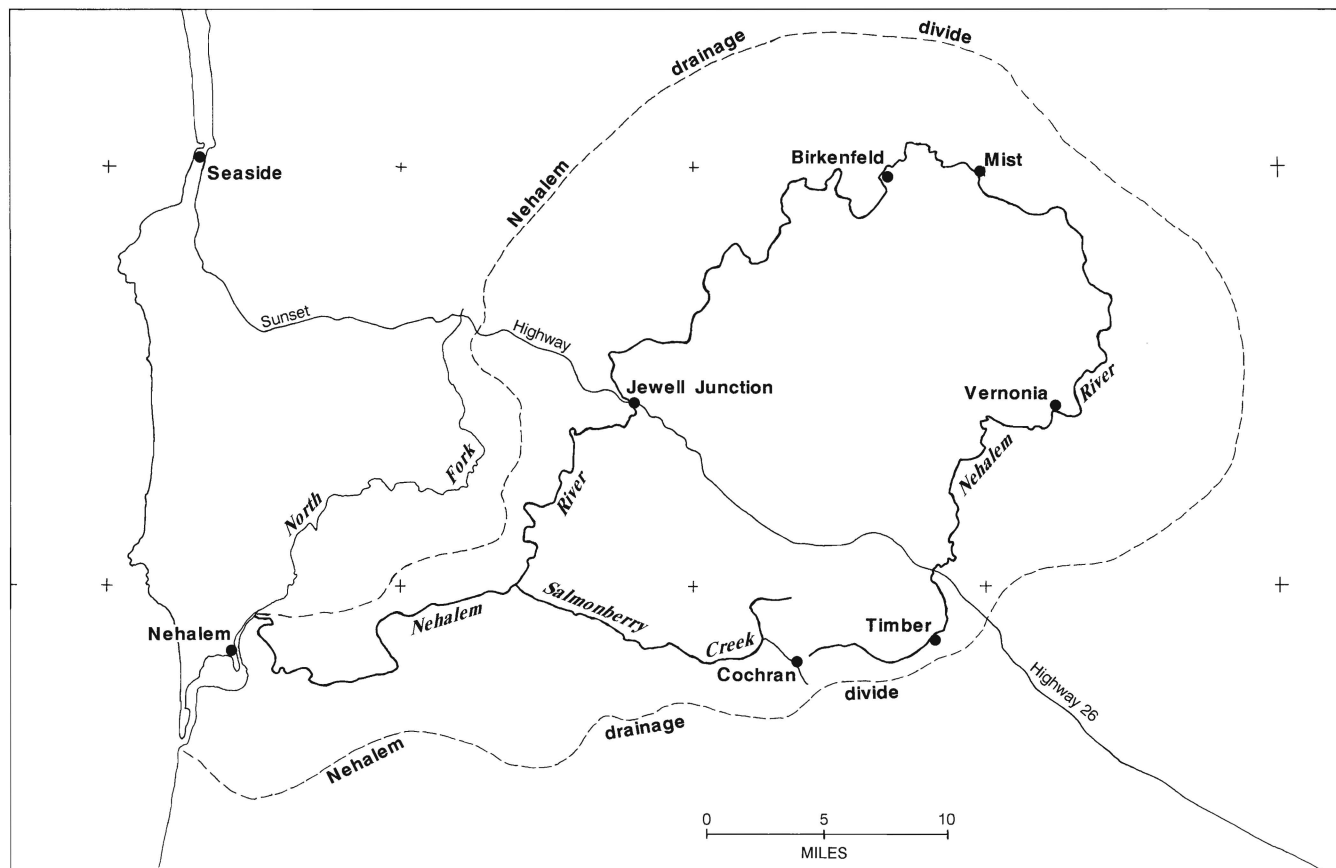


Figure 1. Index map showing counterclockwise course and drainage area of the Nehalem River in northwest Oregon.

dients of stream channels, and changes of drainage divides. Geomorphic features to be studied include presence or absence of meanders (especially when incised), different valley-wall slopes and benches or terraces, upland surfaces of low relief (which used to be called "peneplains"), and barbed tributaries.

Along the Oregon coast, geologic and geomorphic features were studied by Lund (1971, 1972a,b, 1973a,b, 1974a,b, 1975), but within the northern Oregon Coast Range, possibly due to heavy vegetation, the geologic maps of Warren and others (1945), Wells and Peck (1961), and Niem and Niem (1985) are the only ones that have been published, and no geomorphic studies have been made.

Areal geology and bedrock structure ("ground truth") must always be considered whenever geologic maps are available, since bedrock characteristics can affect drainage patterns and result in drainage changes due to differential erosion. Dipping strata can cause lateral migration of valleys. Vertical beds or a fault zone may result in a straight valley course. Tight folding may result in an Appalachian-type trellis pattern, and domal uplift may produce both radial and concentric patterns.

GEOGRAPHY

Careful map measurements on seven 15-minute quadrangles (Birkenfeld, Cathlamet, Enright, Nehalem, Saddle Mountain, Timber, and Vernonia) gave the length of the Nehalem River valley as 88 mi, with a valley gradient of 20 ft per mi (determined by dividing the change in elevation between the start and end of the river, which is 1,808 ft, by the length of the river, which is 88 mi, giving a gradient of approximately 20.5 ft per mi). Repeated, more precise measurements following each meander gave a "channel length" of 121 mi. The average river gradient (1,808 ft divided by 121 mi = 14.9 ft per mi) itself is thus approximately 15 ft per mi.

One tributary of the Salmonberry River rises near Cochran and joins the river, which flows 14 mi westerly to its mouth on the Nehalem at an elevation of 231 ft. The Salmonberry River thus completes the southwest 55° of the 305° Nehalem loop, with a channel gradient of 113 ft per mi (1,808 ft - 231 ft = 1,577 ft divided by 14 mi = 113 ft per mi), 7.53 times that of the Nehalem. The area within this loop is nearly 300 mi², while the area within the Nehalem River drainage (excluding the North Fork) is a little more than twice that.

Average annual rainfall in the northern Coast Range is higher than anywhere else in Oregon, being 110 in. at Nehalem near the mouth of the river and 130 in. at Glenora on the Wilson River, 10 mi southwest of Cochran. West of the main drainage divide of the Coast Range, adiabatic/orographic rainfall is greater than to the east, and stream gradients are steeper since they travel a much shorter distance to the sea. Erosion on the west side of the northern Coast Range could well have been more rapid than anywhere else in the state.

GEOMORPHOLOGY

Barbed tributaries in the Coast Range can indicate stream capture of the headwaters of streams flowing east into the Willamette River. Barbed tributaries on both the South and North Forks of the Salmonberry River suggest that at least 8 mi of the Nehalem has been captured and that the North Fork before its capture at a point 1½ mi west of Cochran once formed the headwaters of the Nehalem River.

The result of such stream captures is that the Coast Range drainage divide here lies farther to the east than anywhere else north of Eugene. At its easternmost limit, the divide now lies within 12 mi of the Columbia River; south of the Nehalem drainage basin, the Coast Range divide lies 15 mi farther to the west. At its northern limit, the Nehalem drainage divide lies only 2 mi south of the Columbia River.

Usually a stream will constantly adjust its course so as to run on the most easily eroded bed rock. The location of a stream then is nearly always a result of such differential erosion of the various kinds (stratigraphy) and the folding and fracturing (structure) of the bed rock. Thus the stream may follow a bed of soft shale lying between more resistant sandstone layers, or it may follow a zone of broken rock caused by a fault or sets of closely spaced joints.

Within the Nehalem drainage basin, upland areas of gently rolling surfaces can be observed on several of the quadrangles. These could be interpreted as remnants of a once continuous, late mature or early old-age erosion surface. Elevations on this surface usually lie between 800 and 1,200 ft, with few ridges and prominences rising above them to above 2,000 ft.

The Nehalem drainage divide is marked by several basaltic prominences reaching nearly 3,000 ft or more. Among these are Saddle Mountain, Humbug Mountain, Onion Peak, Pinochle Peak, Rogers Peak, Larch Mountain, and Round Top.

STRATIGRAPHY AND STRUCTURE

The cast of our detective story must include the geologic formations making up the northern Coast Range, whose names and ages are as follows (Baldwin, 1981):

Miocene (5.3 to 23.7 million years):

Yakima Basalt Subgroup of the Columbia River Basalt Group
Astoria Formation

Miocene and Oligocene:

Scappoose Formation

Oligocene (23.7 to 36.6 million years):

Pittsburg Bluff Formation

Eocene (36.6 to 57.8 million years):

Keasey Formation

Goble Volcanics

Cowlitz Formation

Yamhill Formation

Tillamook Volcanics

Siletz Volcanics

The most important player in this "Case of the Nehalem Loop" is certainly the Keasey Formation, an easily eroded mudstone and shale, with the underlying resistant lavas of the Goble and Tillamook Volcanics and the overlying Pittsburg Bluff sandstones as supporting players and possibly the Yakima Basalt also entering into the plot.

Faulting appears not to have significantly interrupted the contacts of the formations or affected the course of the Nehalem. The relatively straight 25-mi-long, generally east-west course of the Salmonberry and upper Nehalem might suggest this, but such a fracture has not yet been mapped.

CONCLUSIONS

A much simplified history of the main structural feature involving the above formations, as first suggested by Warren and others (1945) and later presented on the state geologic map (Wells and Peck, 1961), indicates that beginning perhaps in late Miocene time, the formations named above began to be arched up into a north-northeast-plunging geanticline.

Millions of years of slow erosion then beveled off this giant fold, reducing it to a surface of low relief, with streams meandering near sea level. Eocene volcanic rocks were exposed in the core of the fold, and outcrops of the later sedimentary formations formed arcuate belts around the plunging north end of the fold. Pliocene and later uplift eventually rejuvenated the streams and incised their meanders into the rising lowlands, etching out valleys in the weaker Keasey Formation.

One resulting deduction (hypothesis no. 3, modified) is that during this second period of uplift and resulting orographically increased rainfall, the Nehalem River captured all the streams that occupied the arcuate belt of Keasey shale during the rapid clockwise

headward erosion of most of the upper part of its valley.

For the 45 mi from Timber to Jewell Junction, the Nehalem River follows this Keasey belt, with the exception of a 10-mi stretch north of Vernonia, where its meanders have cut less than a mile into the Pittsburg Bluff Formation. The lower 40 mi of the valley, from Jewell Junction to Nehalem Bay, is mostly carved in resistant Tillamook Volcanics. The river originally meandered across a surface of low relief, now uplifted to 800-1,000 ft, upon which the major drainage pattern was established as the range began to rise.

The lower course of the river became fixed within the underlying volcanic rocks, but the upper course migrated down-dip on the "slip-off" contact at the base of the Keasey shale, moving the Coast Range drainage divide 10 to 15 mi to the north and east.

Still another possible deduction (hypothesis no. 4) proposes that a middle Miocene Nehalem River, which originally flowed east across a topography of low relief, was diverted north and west by flows of Yakima Basalt that filled a former broad valley of the Columbia River, then located 10-20 mi west and south of its present course. Today, numerous erosional remnants of basalt lie less than 10 mi from the Nehalem River along most of its course.

Whichever hypothesis is finally chosen (and the main purpose of this discussion is to spur further investigation), the Nehalem River remains the longest river within the Oregon Coast Range and the only one with 305° of counterclockwise course.

REFERENCES

- Allen, J.E., 1975, The Wallowa "ice cap" of northeastern Oregon, an exercise in the interpretation of glacial landforms: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 37, no. 12, p. 189-202.
- 1989a, Ice-age glaciers and lakes south of the Columbia River Gorge: Oregon Geology, v. 51, no. 1, p. 12-14.
- 1989b, Northwest topographic maps: Geological Society of the Oregon Country Newsletter, v. 55, no. 11, p. 153-156.
- Baldwin, E.M., 1981, Geology of Oregon, 3rd ed.: Dubuque, Iowa, Kendall/Hunt, 170 p.
- Lund, E.H., 1971, Coastal landforms between Florence and Yachats, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 33, no. 2, p. 21-44.
- 1972a, Coastal landforms between Tillamook Bay and the Columbia River, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 34, no. 11, p. 173-194.
- 1972b, Coastal landforms between Yachats and Newport, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 34, no. 5, p. 73-91.
- 1973a, Landforms along the coast of southern Coos County, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 35, no. 12, p. 189-210.
- 1973b, Oregon coastal dunes between Coos Bay and Sea Lion Point: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 35, no. 5, p. 73-92.
- 1974a, Coastal landforms between Roads End and Tillamook Bay, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 36, no. 11, p. 173-195.
- 1974b, Rock units and coastal landforms between Newport and Lincoln City, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 36, no. 5, p. 69-90.
- 1975, Landforms along the coast of Curry County, Oregon: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 37, no. 4, p. 57-76.
- Niem, A.R., and Niem, W.A., 1985, Oil and gas investigation of the Astoria Basin, Clatsop and northernmost Tillamook Counties, northwest Oregon: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 14, 8 p., 1 map, 1 correlation chart.
- Warren, W.C., Norbistrath, H., and Grivetti, R.M., 1945, Geology of northwestern Oregon west of the Willamette River and north of latitude 45° 15': U.S. Geological Survey Oil and Gas Investigation Map OM-42.
- Wells, F.G., and Peck, D.L., 1961, Geologic map of Oregon west of the 121st meridian: U.S. Geological Survey Miscellaneous Geological Investigations Map I-325. □

Hungarian appeals to mineral collectors

We have received a request from a mineral collector in Budapest, Hungary, and we are passing it on, hoping to reach some collectors interested in contacting this person. His letter is printed below, with a few editorial changes needed to clarify the writer's English.
(Editors)

Budapest, October 30, 1989

I am sorry I cannot write to you in my poor English.

I am a Hungarian mineral collector. That is unusual in Hungary, so it's very difficult for me. In Hungary, we have only few people whose profession is mineral collecting.

In early 1989, the Society for Popularization of Scientific Knowledge approached me, because I have a considerable collection, and they want to make a comprehensive exhibit of my collection. I was happy, but I haven't one perfect, good mineral from your country.

If it were possible for you to send me any mineral from the U.S.A., I would be very happy and grateful, and it would be a great help for my exhibit.

I offer to send Hungarian minerals in exchange. Accurate scientific names with precise locality information (e.g., pegmatite deposits, mineralogy of Nb, Ta, Ti, REE minerals, pegmatite phosphates, feldspars, and minerals of the zeolite group).

In Hungary, we hear very rarely about American minerals. So you can send us what you want. We trust you. Any assistance you can give me in locating literature will also be most appreciated.

Sorry for my poor English again, but I am looking forward to hearing from you soon. Should you wish to send us minerals or literature for our collection, please send them to this address:

Gabor Tompai
Geology
Körösi Csoma ut. 5.
9. em. 27.
H-1102 Budapest
Hungary.

Thanks for your kindness!

Yours very sincerely,

Gabor Tompai □

Financial assistance for geologic studies in Washington available

Awards to help defray expenses will be available in the 1991 fiscal year for original geologic mapping and other geologic studies that are useful to the Washington Division of Geology and Earth Resources in compiling the new geologic map of Washington.

Available funds will be approximately \$15,000 for fiscal year 1991, and awards will be made on the basis of proposals submitted. First priority will be given to proposals for work in areas lying within the northwest and southeast quadrants of the new state geologic map that are currently unmapped, poorly mapped, or poorly understood geologically. Proposals are due by June 4, 1990.

For additional information and suggestions, interested persons may consult with Division staff, specifically J. Eric Schuster, Assistant State Geologist, State Geologic Map Program, Division of Geology and Earth Resources, Department of Natural Resources, Mail Stop PY-12, Olympia, WA 98504, phone (206) 459-6372 or SCAN 585-6372; or Keith L. Stoffel, Geologist, Spokane Field Office, Division of Geology and Earth Resources, Department of Natural Resources, Spokane County Agricultural Center, N. 222 Havana, Spokane, WA 99202, phone (509) 456-3255 or SCAN 545-3255. □

MINERAL EXPLORATION ACTIVITY

Major metal-exploration activity

Date	Project name, company	Project location	Metal	Status
April 1983	Susanville Kappes Cassiday and Associates	Tps. 9, 10 S. Rs. 32, 33 E. Grant County	Gold	Expl
May 1988	Quartz Mountain Wavecrest Resources Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
June 1988	Noonday Ridge Bond Gold	T. 22 S. Rs. 1, 2 E. Lane County	Gold, silver	Expl
September 1988	Angel Camp Wavecrest Resources, Inc.	T. 37 S. R. 16 E. Lake County	Gold	Expl
September 1988	Glass Butte Galactic Services Inc.	Tps. 23, 24 S. R. 23 E. Lake County	Gold	Expl
September 1988	Grassy Mountain Atlas Precious Metals, Inc.	T. 22 S. R. 44 E. Malheur County	Gold	Expl, com
September 1988	Kerby Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	Expl, com
September 1988	QM Chevron Resources, Co.	T. 25 S. R. 43 E. Malheur County	Gold	Expl
October 1988	Bear Creek Freeport McMoRan Gold Co.	Tps. 18, 19 S. R. 18 E. Crook County	Gold	Expl
December 1988	Harper Basin American Copper and Nickel Co.	T. 21 S. R. 42 E. Malheur County	Gold	Expl
January 1989	Silver Peak Formosa Exploration, Inc.	T. 31 S. R. 6 W. Douglas County	Copper, zinc	App, com
May 1989	Hope Butte Chevron Resources, Co.	T. 17 S. R. 43 E. Malheur County	Gold	Expl, com
September 1989	East Ridge Malheur Mining	T. 15 S. R. 45 E. Malheur County	Gold	App
March 1990	Red Jacket Bond Gold	T. 9 S. R. 17 E. Jefferson County	Gold	App

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

Exploration and bond ceiling rule making

Advisory committees organized to make recommendations on exploration permits (HB 2088) and bond ceilings for some metal mines (SB 354) finished their work in April. For a copy of either set of draft rules or a schedule of rulemaking hearings, contact Doris Brown at the Oregon Department of Geology and Mineral Industries (DOGAMI) Mined Land Reclamation Office, 1534 Queen Avenue SE, Albany, OR 97321, phone (503) 967-2039.

Mining issues forum

A steering committee has been established to determine the format, time, and location of the forum. The committee is composed of representatives from environmental groups, mining companies, regulatory agencies, and state and local elected officials. Additional information will be presented in future issues of *Oregon Geology*.

Status changes

The operating-permit application for the Formosa Exploration Silver Peak mine has been determined to be complete and adequate. The permit will be issued upon receipt of the financial security. A summary of the operation and permit is available from the MLR office for comments.

The meeting of the project coordinating committee for the Hope Butte project by Chevron was rescheduled from February to May. Bond Gold has applied for an exploration permit in Jefferson County.

All readers who have questions or comments about exploration activity should contact Gary Lynch or Allen Throop at the MLR office in Albany, phone (503) 967-2039. □

New field trip guides for Oregon published

Field excursions to volcanic terranes in the western United States, Volume II: Cascades and Intermountain West.

Published by New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801, Memoir 47, \$17 plus \$1.50 for postage and handling.

The geology of some volcanic terranes in Oregon is presented in field trip guides included in this recent publication: (1) a one-day trip from Hood River to Portland via Mount Hood, with optional side trips to Old Maid Flat and Mount Tabor/Boring Lava exposures; and (2) three legs of a Southern Cascades trip leading from Klamath Falls through Klamath Basin to Crater Lake and through the Western Cascades to Medford and Siskiyou Pass.

The field trip guides are part of volume II in a two-volume set, Memoirs 46 and 47 of the New Mexico Bureau of Mines and Mineral Resources. They were published in conjunction with the General Assembly of the International Association of Volcanology and Chemistry of the Earth's Interior held in June 1989 at Santa Fe, New Mexico.

Guidebook for field trip to the Mount Bachelor-South Sister-Bend area, central Oregon High Cascades.

Published by U.S. Geological Survey, Open-File Report 89-645, available for \$10.25 from U.S. Geological Survey Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO 80225.

This field guide to the central Oregon High Cascades highlights aspects of the volcanic and glacial history in the vicinity of Mount Bachelor (formerly Bachelor Butte), South Sister, and Bend.

The three one-day field excursions were conducted on the occasion of the Fall 1989 Meeting of the Friends of the Pleistocene. Each field trip log begins at Little Fawn Campground, a group campground run by the USDA Forest Service on the south end of Elk Lake near Mount Bachelor. □

(Proceedings, continued from page 50)

states of Oregon, Washington, Idaho, Montana, and the Province of British Columbia, and in Virginia, where the 26th Forum is scheduled to be held in May of this year. Seven papers describe specific commodities such as bentonite, limestone, pozzolans, rare earths, talc, and zeolites. Three papers discuss various methods and problems in laboratory analysis of industrial minerals.

The new publication, DOGAMI Special Paper 23, is 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 \$9. 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. □

AVAILABLE DEPARTMENT PUBLICATIONS

GEOLOGICAL MAP SERIES

	Price ✓
GMS-4 Oregon gravity maps, onshore and offshore. 1967	3.00
GMS-5 Geologic map, Powers 15-minute Quadrangle, Coos/Curry Counties. 1971	3.00
GMS-6 Preliminary report on geology of part of Snake River canyon. 1974	6.50
GMS-8 Complete Bouguer gravity anomaly map, central Cascade Mountain Range. 1978	3.00
GMS-9 Total-field aeromagnetic anomaly map, central Cascade Mountain Range. 1978	3.00
GMS-10 Low- to intermediate-temperature thermal springs and wells in Oregon. 1978	3.00
GMS-12 Geologic map of the Oregon part of the Mineral 15-minute Quadrangle, Baker County. 1978	3.00
GMS-13 Geologic map, Huntington and parts of Olds Ferry 15-minute Quadrangles, Baker and Malheur Counties. 1979	3.00
GMS-14 Index to published geologic mapping in Oregon, 1898-1979. 1981	7.00
GMS-15 Free-air gravity anomaly map and complete Bouguer gravity anomaly map, north Cascades, Oregon. 1981	3.00
GMS-16 Free-air gravity and complete Bouguer gravity anomaly maps, south Cascades, Oregon. 1981	3.00
GMS-17 Total-field aeromagnetic anomaly map, southern Cascades, Oregon. 1981	3.00
GMS-18 Geology of Rickreall/Salem West/Monmouth/Sidney 7½-minute Quadrangles, Marion/Polk Counties. 1981	5.00
GMS-19 Geology and gold deposits map, Bourne 7½-minute Quadrangle, Baker County. 1982	5.00
GMS-20 Geology and geothermal resources, S½ Burns 15-minute Quadrangle, Harney County. 1982	5.00
GMS-21 Geology and geothermal resources map, Vale East 7½-minute Quadrangle, Malheur County. 1982	5.00
GMS-22 Geology and mineral resources map, Mount Ireland 7½-minute Quadrangle, Baker/Grant Counties. 1982	5.00
GMS-23 Geologic map, Sheridan 7½-minute Quadrangle, Polk and Yamhill Counties. 1982	5.00
GMS-24 Geologic map, Grand Ronde 7½-minute Quadrangle, Polk and Yamhill Counties. 1982	5.00
GMS-25 Geology and gold deposits map, Granite 7½-minute Quadrangle, Grant County. 1982	5.00
GMS-26 Residual gravity maps, northern, central, and southern Oregon Cascades. 1982	5.00
GMS-27 Geologic and neotectonic evaluation of north-central Oregon. The Dalles 1° x 2° Quadrangle. 1982	6.00
GMS-28 Geology and gold deposits map, Greenhorn 7½-minute Quadrangle, Baker and Grant Counties. 1983	5.00
GMS-29 Geology and gold deposits map, NE¼ Bates 15-minute Quadrangle, Baker and Grant Counties. 1983	5.00
GMS-30 Geologic map, SE¼ Pearsoll Peak 15-minute Quadrangle, Curry and Josephine Counties. 1984	6.00
GMS-31 Geology and gold deposits map, NW¼ Bates 15-minute Quadrangle, Grant County. 1984	5.00
GMS-32 Geologic map, Wilhoit 7½-minute Quadrangle, Clackamas and Marion Counties. 1984	4.00
GMS-33 Geologic map, Scotts Mills 7½-minute Quadrangle, Clackamas and Marion Counties. 1984	4.00
GMS-34 Geologic map, Stayton NE 7½-minute Quadrangle, Marion County. 1984	4.00
GMS-35 Geology and gold deposits map, SW¼ Bates 15-minute Quadrangle, Grant County. 1984	5.00
GMS-36 Mineral resources map of Oregon. 1984	8.00
GMS-37 Mineral resources map, offshore Oregon. 1985	6.00
GMS-38 Geologic map, NW¼ Cave Junction 15-minute Quadrangle, Josephine County. 1986	6.00
GMS-39 Geologic bibliography and index maps, ocean floor and continental margin off Oregon. 1986	5.00
GMS-40 Total-field aeromagnetic anomaly maps, Cascade Mountain Range, northern Oregon. 1985	4.00
GMS-41 Geology and mineral resources map, Elkhorn Peak 7½-minute Quadrangle, Baker County. 1987	6.00
GMS-42 Geologic map, ocean floor off Oregon and adjacent continental margin. 1986	8.00
GMS-43 Geologic map, Eagle Butte and Gateway 7½-minute Quadrangles, Jefferson and Wasco Counties. 1987	4.00
GMS-44 Geologic map, Seekseequa Junction and Metolius Bench 7½-minute Quadrangles, Jefferson County. 1987	4.00
GMS-45 Geologic map, Madras West and Madras East 7½-minute Quadrangles, Jefferson County. 1987	4.00
GMS-46 Geologic map, Breitenbush River area, Linn and Marion Counties. 1987	6.00

GMS-47 Geologic map, Crescent Mountain, Linn County. 1987	6.00
GMS-48 Geologic map, McKenzie Bridge 15-minute Quadrangle, Lane County. 1988	8.00
GMS-49 Map of Oregon seismicity, 1841-1986. 1987	3.00
GMS-50 Geologic map, Drake Crossing 7½-minute Quadrangle, Marion County. 1986	4.00
GMS-51 Geologic map, Elk Prairie 7½-minute Quadrangle, Marion/Clackamas Counties. 1986	4.00
GMS-53 Geology and mineral resources map, Owyhee Ridge 7½-minute Quadrangle, Malheur County. 1988	4.00
GMS-54 Geology and mineral resources map, Graveyard Point 7½-minute Quadrangle, Malheur and Owyhee Counties. 1988	4.00
GMS-55 Geology and mineral resources map, Owyhee Dam 7½-minute Quadrangle, Malheur County. 1989	4.00
GMS-56 Geology and mineral resources map, Adrian 7½-minute Quadrangle, Malheur County. 1989	4.00
GMS-57 Geology and mineral resources map, Grassy Mountain 7½-minute Quadrangle, Malheur County. 1989	4.00
GMS-58 Geology and mineral resources map, Double Mountain 7½-minute Quadrangle, Malheur County. 1989	4.00
GMS-59 Geologic map, Lake Oswego 7½-minute Quadrangle, Clackamas, Multnomah, and Washington Counties. 1989	6.00

BULLETINS

33 Bibliography of geology and mineral resources of Oregon (1st supplement, 1936-45). 1947	3.00
35 Geology of the Dallas and Valseltz 15-minute Quadrangles, Polk County (map only). Revised 1964	3.00
36 Papers on Foraminifera from the Tertiary (v. 2 [parts VII-VIII] only). 1949	3.00
44 Bibliography of geology and mineral resources of Oregon (2nd supplement, 1946-50). 1953	3.00
46 Ferruginous bauxite, Salem Hills, Marion County. 1956	3.00
53 Bibliography of geology and mineral resources of Oregon (3rd supplement, 1951-55). 1962	3.00
61 Gold and silver in Oregon. 1968 (reprint)	17.50
65 Proceedings of the Andesite Conference. 1969	10.00
67 Bibliography of geology and mineral resources of Oregon (4th supplement, 1956-60). 1970	3.00
71 Geology of selected lava tubes, Bend area, Deschutes County. 1947	5.00
78 Bibliography of geology and mineral resources of Oregon (5th supplement, 1961-70). 1973	3.00
81 Environmental geology of Lincoln County. 1973	9.00
82 Geologic hazards of Bull Run Watershed, Multnomah and Clackamas Counties. 1974	6.50
87 Environmental geology, western Coos/Douglas Counties. 1975	9.00
88 Geology and mineral resources, upper Chetco River drainage, Curry and Josephine Counties. 1975	4.00
89 Geology and mineral resources of Deschutes County. 1976	6.50
90 Land use geology of western Curry County. 1976	9.00
91 Geologic hazards of parts of northern Hood River, Wasco, and Sherman Counties. 1977	8.00
92 Fossils in Oregon. A collection of reprints from the <i>Ore Bin</i> . 1977	4.00
93 Geology, mineral resources, and rock material of Curry County. 1977	7.00
94 Land use geology, central Jackson County. 1977	9.00
95 North American ophiolites (IGCP project). 1977	7.00
96 Magma genesis. AGU Chapman Conference on Partial Melting. 1977	2.50
97 Bibliography of geology and mineral resources of Oregon (6th supplement, 1971-75). 1978	3.00
98 Geologic hazards, eastern Benton County. 1979	9.00
99 Geologic hazards of northwestern Clackamas County. 1979	10.00
100 Geology and mineral resources of Josephine County. 1979	9.00
101 Geologic field trips in western Oregon and southwestern Washington. 1980	9.00
102 Bibliography of geology and mineral resources of Oregon (7th supplement, 1976-79). 1981	4.00
103 Bibliography of geology and mineral resources of Oregon (8th supplement, 1980-84). 1987	7.00

MISCELLANEOUS PAPERS

5 Oregon's gold placers. 1954	1.00
11 Articles on meteorites (reprints from the <i>Ore Bin</i>). 1968	3.00
15 Quicksilver deposits in Oregon. 1971	3.00
19 Geothermal exploration studies in Oregon, 1976. 1977	3.00
20 Investigations of nickel in Oregon. 1978	5.00

SHORT PAPERS

25 Petrography of Rattlesnake Formation at type area. 1976	3.00
27 Rock material resources of Benton County. 1978	4.00

AVAILABLE DEPARTMENT PUBLICATIONS (continued)

SPECIAL PAPERS

	Price ✓
2 Field geology, SW Broken Top Quadrangle. 1978	3.50
3 Rock material resources, Clackamas, Columbia, Multnomah, and Washington Counties. 1978	7.00
4 Heat flow of Oregon. 1978	3.00
5 Analysis and forecasts of demand for rock materials. 1979	3.00
6 Geology of the La Grande area. 1980	5.00
7 Pluvial Fort Rock Lake, Lake County. 1979	4.00
8 Geology and geochemistry of the Mount Hood volcano. 1980	3.00
9 Geology of the Breitenbush Hot Springs Quadrangle. 1980	4.00
10 Tectonic rotation of the Oregon Western Cascades. 1980	3.00
11 Theses and dissertations on geology of Oregon. Bibliography and index, 1899-1982	6.00
12 Geologic linears, N part of Cascade Range, Oregon. 1980	3.00
13 Faults and lineaments of southern Cascades, Oregon. 1981	4.00
14 Geology and geothermal resources, Mount Hood area. 1982	7.00
15 Geology and geothermal resources, central Cascades. 1983	11.00
16 Index to the <i>Ore Bin</i> (1939-1978) and <i>Oregon Geology</i> (1979-1982). 1983	4.00
17 Bibliography of Oregon paleontology, 1792-1983. 1984	6.00
18 Investigations of talc in Oregon. 1988	7.00
19 Limestone deposits in Oregon. 1989	8.00
20 Bentonite in Oregon: Occurrences, analyses, and economic potential. 1989	6.00
21 Field geology of the NW¼ Broken Top 15-minute Quadrangle, Deschutes County. 1987	5.00
23 Industrial rocks and minerals of the Pacific Northwest. 25th Forum on Geology of Industrial Minerals, 1989, Proceedings. 1990	9.00

OIL AND GAS INVESTIGATIONS

3 Preliminary identifications of Foraminifera, General Petroleum Long Bell #1 well. 1973	3.00
4 Preliminary identifications of Foraminifera, E.M. Warren Coos County 1-7 well. 1973	3.00
5 Prospects for natural gas, upper Nehalem River Basin. 1976	5.00
6 Prospects for oil and gas, Coos Basin. 1980	9.00
7 Correlation of Cenozoic stratigraphic units of western Oregon and Washington. 1983	8.00

8 Subsurface stratigraphy of the Ochoco Basin, Oregon. 1984	7.00
9 Subsurface biostratigraphy of the east Nehalem Basin. 1983	6.00
10 Mist Gas Field: Exploration/ development, 1979-1984. 1985	4.00
11 Biostratigraphy of exploratory wells, western Coos, Douglas, and Lane Counties. 1984	6.00
12 Biostratigraphy, exploratory wells, N Willamette Basin. 1984	6.00
13 Biostratigraphy, exploratory wells, S Willamette Basin. 1985	6.00
14 Oil and gas investigation of the Astoria Basin, Clatsop and northernmost Tillamook Counties. 1985	7.00
15 Hydrocarbon exploration and occurrences in Oregon. 1989	7.00
16 Available well records and samples, onshore and offshore oil and gas wells. 1987	5.00

MISCELLANEOUS PUBLICATIONS

Geologic map of Oregon east of 121st meridian (U.S. Geological Survey Map I-902). 1977 (blackline copy only)	6.10
Geologic map of Oregon west of 121st meridian (U.S. Geological Survey Map I-325). 1961 (blackline copy only)	6.10
Geological highway map, Pacific Northwest region, Oregon, Washington, and part of Idaho (published by AAPG). 1973	5.00
Landforms of Oregon (relief map, 17x12 in.). revised 1990	1.00
Oregon Landsat mosaic map (published by ERSAL, OSU). 1983	10.00
Geothermal resources of Oregon (published by NOAA). 1982	3.00
Index map of available topographic maps for Oregon published by the U.S. Geological Survey	1.50
Bend 30-minute Quadrangle geologic map and central Oregon High Cascades reconnaissance geologic map. 1957	3.00
Lebanon 15-minute Quad., Reconnaissance geologic map. 1956	3.00
Mist Gas Field Map, showing well locations, revised 1990 (Open-File Report O-90-1, ozalid print, incl. production data)	7.00
Northwest Oregon, Correlation Section 24. Bruer and others, 1984 (published by AAPG)	5.00
Oregon rocks and minerals, a description. 1988 (DOGAMI Open-File Report O-88-6; rev. ed. of Miscellaneous Paper 1)	5.00
Mining claims (State laws governing quartz and placer claims)	Free
Back issues of <i>Ore Bin/Oregon Geology</i> , 1939-April 1988	1.00
Back issues of <i>Oregon Geology</i> , May/June 1988 and later	2.00
Color postcard: Oregon State Rock and State Gemstone	.50

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

ORDER AND RENEWAL FORM

Check desired publications in list above and enter total amount below. Minimum mail order \$1.00. All sales are final. Publications are sent postpaid. Payment must accompany orders of less than \$50. On credit card orders, a handling fee of 10% will be added. Subscription price for *Oregon Geology*: \$6 for 1 year, \$15 for 3 years. Make payment in U.S. dollars only.

Amount enclosed: \$_____ for (check appropriate space):

Publications marked above____. Renewal of current subscription____ / new subscription____ to *Oregon Geology*.

Name_____

Address_____

City/State/Zip_____

Please charge to Visa____ / Mastercard____, account number:

Expiration date:

Cardholder's signature_____