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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted. If manuscript was prepared on common word-processing equipment, a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, high-density diskette only). Graphics should be camera ready; photographs should be black-and-white glossies. All figures should be clearly marked; figure captions should be together at the end of the text.

Style is generally that of U.S. Geological Survey publications. (See USGS *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) Bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Include names of reviewers in the acknowledgments.

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

Cover photo

George Priest, western regional geologist for DOGAMI, discusses details of new geologic marker describing tsunamis and their occurrences in the Reedsport area. The marker is located at the Tourist Information Center in Reedsport and was unveiled and dedicated February 4, 1995. Similar markers have been placed in Seaside and Newport. This issue contains several articles that address the subject of tsunamis as a coastal catastrophic hazard.

In memoriam: Margaret Steere

Margaret Steere, geologist and geologic editor with the Oregon Department of Geology and Mineral Industries (DOGAMI) for almost 30 years, died of pneumonia on January 29, 1995. A native of Muskegon, Michigan, Margaret received her bachelor's and master's degrees in geology from the University of Michigan. She came to Oregon during World War II and worked as a cartographer for the U.S. Army Corps of Engineers. She joined the DOGAMI staff in October of 1947, working first as a librarian and later as geologist and geologic editor. She retired from DOGAMI in 1977 but returned in 1991 as a volunteer, donating 691 hours of volunteer service.

Margaret L. Steere

During her working years with DOGAMI, Margaret produced over 300 issues of the *Ore Bin,* DOGAMI's monthly publication, and edited almost 60 Bulletins, plus numerous other Short Papers, Miscellaneous Papers, Oil and Gas Investigations, geologic maps, and open-file reports. Her knowledge of geology, ability to organize, mastery of language, sense of humor, and endless patience enabled her to bring these detailed publications to press, often under difficult circumstances. Although paleontology was not her original focus in geology, she became the resident expert because there was a need for paleontological knowledge in DOGAMI. Her articles on fossils were some of the most popular articles in the *Ore Bin.* Bulletin 92, *Fossils in Oregon,* which contains reprints of many of her articles, is still one of DOGAMI's most popular publications.

In addition to her work on publications, she had responsibility for maintaining the DOGAMI museum and devoted many hours to curating the collection. Her work with publications, the museum collection, and paleontology put her in contact with many of the major geologists of her time. Correspondence found in her files shows the respect and appreciation that many of these geologists felt for her work.

During her retirement, she was an active member of the Geological Society of the Oregon Country, often working behind the scenes to see that work that needed to be done was done properly. She also developed considerable skill as a water colorist. When

(Continued on page 32)

Oil and gas exploration and development in Oregon, 1994

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

ABSTRACT

Oil and gas leasing activity was about the same during 1994 as it was in 1993. Four U.S. Bureau of Land Management (BLM) lease sales were held, but no leases were purchased. No over-the-counter filings for BLM leases were received during the year. A total of seven federal tracts were under lease at year's end and consisted of a total of 3,728 acres. The State of Oregon conducted no lease auctions during the year. A total of 16 State of Oregon tracts were under lease at year's end and consisted of 25,520 acres, which is the same as in 1993. Columbia County held an auction during the year at which 17 tracts comprising a total of 5,060 acres were leased. Bids ranged from $2.50 to $41.00 per acre, and Nahama and Weagant Energy Company, Bakersfield, California, acquired the majority of the acreage.

During 1994, no exploratory wells were drilled, primarily due to the fact that Nahama and Weagant Energy Company, operator of the Mist Gas Field, filed for bankruptcy under Chapter 7 of the Federal Bankruptcy Code. Operations at Mist Gas Field included reclaiming three dry-hole drill sites and plugging and reclaiming the drill site of a depleted former gas producer. Carbon Energy International, Dallas, Texas, plugged and reclaimed the drill sites of two wells in the Coos Basin during the year.

At the Mist Gas Field, 21 wells were productive during the year, and three suspended wells awaited pipeline connection at year's end. One of the most significant developments during 1994 was the installation of a Nitrogen Rejection Unit (NRU) at Mist Gas Field, which enabled three low-Btu (British thermal unit) wells to be put into production. As a consequence, a total of 4.2 billion cubic feet (Bcf) of gas was produced during 1994, an increase over the 3.5 Bcf produced during 1993. Value of the gas produced during the year declined to $6.4 million from the $7.1 million during 1993, due to a drop in the price per therm for the gas.

The Oregon Department of Geology and Mineral Industries (DOGAMI) completed a study of the Tyee Basin located in Douglas and Coos Counties. Final data, reports, and maps on the oil, gas, and coal resources of the area are expected to be published by the end of 1995.

During 1994, DOGAMI conducted its triennial review of the administrative rules related to oil and gas operations. As a result, the agency has proposed a number of changes, the most significant of which is the elimination of drilling units. In addition, DOGAMI has proposed 1995 legislation that would allow cost recovery for extraordinary expenses related to oil and gas regulatory activities in Oregon.

LEASING ACTIVITY

Oil and gas leasing activity was about the same during 1994 as it was in 1993. This is the continuation of a generally declining trend in leasing activity that began during the late 1980s. Activity included four public sales by BLM; however, no bids were received at these sales. BLM received no over-the-counter lease-filing applications during the year.

A total of seven federal tracts were under lease at year's end and consisted of a total of 3,728 acres. This is a decrease from the 5,491 federal acres under lease at the end of 1993. Total rental income was $3,769. At year's end, applications on 39,942 federal acres were pending.

Nahama and Weagant Energy Co. abandoned the Longview Fibre 23–25 well, a depleted gas producer at the Mist Gas Field. During its 6-year productive period, the well produced about 0.3 Bcf gas, which sold for over one million dollars.

The State of Oregon held no lease sales during the year; it had held no lease sales during 1993, either. With no changes during the year, a total of 16 State of Oregon tracts (25,520 acres) were under lease at year's end, and total rental income was about $25,520—the same as in 1993.

Columbia County held an auction during July, at which 17 tracts representing a total of 5,060 acres were leased. Nahama and Weagant Energy Company was the highest bidder on 13 tracts consisting of 3,196 acres, with bids ranging from $2.50 to $3.50 per acre. Oregon Natural Gas Development Company, Portland, Oregon, made a successful bid of $2.50 per acre on two tracts consisting of 830 acres. Anders Elgard, Lakewood, Colorado, placed the highest bids at the auction, offering $22.00 and $41.00 per acre and acquiring two tracts totaling 1,034 acres.

Table 1. *Oil and gas permit activity in Oregon, 1994*

Permit no.	Operator, well, API number	Location	Date issued	Status, depth (ft) TD=total depth PTD=proposed TD	Date canceled, reason
338	Nahama and Weagant Longview Fibre 23-25 36-009-00179	SW¼ sec. 25 T. 6 N., R. 5 W. Columbia County	9-30-85	Abandoned, depleted producer; TD=1,979	—
472	Nahama and Weagant CC 41-33-75 36-009-00297	NE¼ sec. 33 T. 7 N., R. 5 W. Columbia County	7-6-92	—	Canceled, 7-6-94; expired.
479	Nahama and Weagant CC 42-32-74 36-009-00304	NE¼ sec. 32 T. 7 N., R. 4 W. Columbia County	4-25-93	—	Canceled, 4-26-94; expired.
480	Nahama and Weagant CC 43-8-64 36-009-00305	SE¼ sec. 8 T. 6 N., R. 4 W. Columbia County	5-19-93	—	Canceled, 5-19-94; expired.
484	Nahama and Weagant CC 42-34-65 36-009-00309	NE¼ sec. 34 T. 6 N., R. 5 W. Columbia County	5-19-93	—	Canceled, 5-19-94; expired.
486	Carbon Energy WNS- Menasha 32-1 36-011-00026	SW¼ sec. 32 T. 26 S., R. 13 W. Coos County	9-30-93	Abandoned, dry hole; TD=1,594	—
487	Carbon Energy Coos Co. Forest 7-1 36-011-00027	SE¼ sec. 7 T. 27 S., R. 13 W. Coos County	9-7-93	Abandoned dry hole; TD=3,993	—
488	Nahama and Weagant Adams 14-31-74 36-009-00310	SW¼ sec. 31 T. 7 N., R. 4 W. Columbia County	6-28-93	—	Canceled, 6-28-94; expired.
489	Nahama and Weagant HNR 42-27-64 36-009-00311	NE¼ sec. 27 T. 6 N., R. 4 W. Columbia County	6-28-93	—	Canceled, 6-28-94; expired.
491	Nahama and Weagant HNR 31-21-64 36-009-00313	NE¼ sec. 21 T. 6 N., R. 4 W. Columbia County	7-6-93	—	Canceled, 7-6-94; expired.
492	Nahama and Weagant CFW 23-33-74 36-009-00314	SW¼ sec. 33 T. 7 N., R. 4 W. Columbia County	6-28-93	—	Canceled, 6-28-94; expired.
494	Nahama and Weagant Hemeon 13-14-65 30-009-00316	SW¼ sec. 14 T. 6 N., R. 5 W. Columbia County	9-27-93	—	Canceled, 9-27-94; expired.
497	Nahama and Weagant LF 21-32-75 36-009-00319	NW¼ sec. 32 T. 7 N., R. 5 W. Columbia County	10-20-93	—	Canceled, 10-20-94; expired.

DRILLING

For the first year since 1974, no exploratory oil and gas wells were drilled in Oregon. This is largely attributed to the fact that Nahama and Weagant Energy Company, operator of the Mist Gas Field and driller of thirteen exploratory gas wells and three redrills in 1993, filed for bankruptcy under Chapter 7 of the Federal Bankruptcy Code during the year. A court-appointed trustee has been assigned to sell the assets of Nahama and Weagant Energy Company, including the Mist Gas Field. It was reported that several bids for the Mist Gas Field were received and that the successful bidder, who will become the field operator, would be named during 1995.

Operations at the Mist Gas Field during 1994 included the reclaiming by Nahama and Weagant Energy Company, in partnership with Oregon Natural Gas Development Company, of three drill sites of abandoned wells drilled during 1993. In addition, Nahama and Weagant Energy abandoned and reclaimed the drill site of a depleted former gas producer, the well Longview Fibre 23–25, located in SW¼ sec. 25, T. 6 N., R. 5 W., Columbia County.

In the Coos Basin, Carbon Energy International during 1994 completed testing operations and abandoned the two exploratory

Carbon Energy International well Coos County Forest 7–1, which was drilled during 1993. Testing showed only noncommercial quantities of gas, and the well has now been abandoned.

coal-bed methane gas test wells drilled during 1993. These wells, the Coos County Forest 7–1, located in SE¼ sec. 7, T. 27 S., R. 13 W., and the WNS-Menasha 32–1, located in SW¼ sec. 32, T. 26 S., R. 13 W., had reported shows of natural gas, but test results failed to establish economically productive rates. The wells were plugged and abandoned, and the drill sites were reclaimed.

During 1994, DOGAMI did not issue any permits to drill, while 10 permits were canceled. Permit activity is listed in Table 1.

DISCOVERIES AND GAS PRODUCTION

Despite the bankruptcy filing by Nahama and Weagant Energy Company, the Mist Gas Field operated normally during the year. One of the most significant developments during 1994 was the installation of a Nitrogen Rejection Unit (NRU) at the Mist Gas Field. The NRU is operated as a joint venture between Nahama and Weagant Energy Company, Oregon Natural Gas Development Company, and BCCK Engineering, the company that designed and installed the unit. The NRU operates by lowering the temperature of the produced gas, which consists of a mixture of methane and noncombustible nitrogen. The methane, having the higher freezing temperable of the two gases, freezes first, and the nitrogen gas is vented to the atmosphere. The result is almost pure methane gas. The NRU has enabled three low-Btu wells to go into production. A Btu is the measure of the heating value of natural gas; pure methane has a Btu of 1,012.

The three low-Btu wells that Nahama and Weagant Energy Company put into production during 1994 are located in the southern portion of the Mist Gas Field. The wells are the CFI 23–15, located in SW¼ sec. 15, T. 5 N., R. 4 W., with a Btu of 651; the CFI 31–16, located in NE¼ sec. 16, T. 5 N., R. 4 W., with a Btu of 537; and the CC 42–8–54, located in NE¼ sec. 8, T. 5 N., R. 4 W., with a Btu of 691. With the installation of the NRU, the gas produced from these wells is increased to approximately 1,000 Btu by the removal of the noncombustible nitrogen.

The Mist Gas Field had 21 productive gas wells during 1994, and three wells awaited pipeline connection at year's end. Gas production for the year totaled 4.2 Bcf of gas, an increase from the 3.5 Bcf produced during 1993. The cumulative field production as of the end of 1994 was 54.0 Bcf. The total value of the gas produced for the year was $6.4 million, a decline from the $7.1 million during 1993. This decline is the result of a drop in gas prices during the year to a range from 11 to 23 cents per therm, which is less than the 16 to 25 cents per therm for which gas sold last year. Cumulatively, the total value of gas produced since the Mist Gas Field was discovered in 1979 is about $111 million.

GAS STORAGE

The Mist Natural Gas Storage Project remained fully operational during 1994. The gas storage project has nine injection-withdrawal service wells, five in the Bruer Pool and four in the Flora Pool, and thirteen observation-monitor service wells. The two pools have a combined storage capacity of 10 Bcf of gas. This allows for the cycling of about 6 Bcf in the reservoirs at pressures between approximately 400 and 1,000 psi and will provide for an annual delivery of 1 million therms of gas per day for 100 days. During 1994, about 5,956,409 cubic feet of gas was injected,, and 5,236,505 cubic feet was withdrawn at the Mist Gas Storage Project. Plans are underway to develop a third gas storage unit at the Mist Gas Field. Two gas wells, the Nahama and Weagant Energy

Nahama and Weagant Energy reclaimed the drill site of the well Libel 32–15–65, drilled at the Mist Gas Field during 1993 as a dry hole.

Company CC 14–23 located in SW¼ sec. 23, T. 6 N., R. 5 W., and CC 23–22 located in SW¼ sec. 22, T. 6 N., R. 5 W., were shut in during 1994 and will be part of the new gas storage project.

OTHER ACTIVITIES

DOGAMI completed a five-year study of the oil, gas, and coal resource potential of the Tyee Basin located in Douglas and Coos Counties in the southern Coast Range. The study, which was funded by landowners in the study area and by county, state, and federal agencies in a public-private partnership, is an investigation of source rock, stratigraphy, and structural framework for those characteristics that are needed to generate and trap oil and gas. The final data, reports, and maps are expected to be published by DOGAMI by the end of 1995. A series of maps and preliminary reports that present a revised understanding of the geologic framework of the Tyee Basin have already been published (see publication list at end of report).

DOGAMI and the Northwest Petroleum Association (NWPA) sponsored a series of meetings at which the U.S. Geological Survey and Minerals Management Service discussed work on a national assessment of undiscovered oil and gas reserves including the Pacific Northwest. The assessment is using a methodology in which oil and gas plays are evaluated for their future potential reserves. Work continues on the assessment, and a draft report is expected to be released during 1995. Individuals interested in oil and gas resources in the Pacific Northwest should contact DOGAMI or the NWPA for details.

The NWPA remained active for the year and has over 100 members. At its regular monthly meetings, speakers give talks generally related to energy matters in the Pacific Northwest. The 1994 symposium was held in Port Angeles, Washington, on the geology of the Strait of Juan de Fuca, and plans are now underway for the 1995 symposium.

For information, contact the NWPA, P.O. Box 6679, Portland, OR 97228.

DOGAMI completed its triennial review of the administrative rules related to oil and gas operations in Oregon and proposed a number of changes. The most significant change is eliminating the requirement for drilling units, which was considered an unneeded regulation. Other revisions proposed by DOGAMI, the oil and gas industry, and interested individuals are generally associated with administrative changes. In addition, DOGAMI has proposed 1995 legislation that would allow cost recovery for extraordinary expenses related to oil and gas regulatory activities. Examples of extraordinary expenses are the cost of of engineering and geologic documents and legal expenses; administrative costs related to regulatory work for public hearings, for administering spacing units, integration orders, or unit operations when requested by an operator. Contact DOGAMI for details regarding proposed changes either to the administrative rules or the 1995 legislation.

PUBLICATIONS FROM THE TYEE BASIN STUDY

Black, G.L., 1990, Geologic map of the Reston quadrangle, Douglas County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–68, 4 p., map scale 1:24,000.

———1994, Geologic map of the Kenyon Mountain quadrangle, Douglas and Coos Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series

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Tsunami survey conducted by DOGAMI

by Angie Karel, Oregon Department of Geology and Mineral Industries, Portland OR 97232

The Oregon Department of Geology and Mineral Industries (DOGAMI) is becoming increasingly concerned about the risk to people and property posed by large offshore earthquakes that can be expected to result in damaging tsunamis ("tidal waves").

The Department was interested in determining if any type of tsunami preparedness education or evacuation drills were currently being taught in Oregon coastal schools. Proposed survey questions were developed by Department staff and peer reviewed by Al Shannon, Oregon Department of Education; Sherry Patterson, Earthquake Preparedness Network; and Peg Reagan, Curry County Commissioner serving on the Oregon Seismic Safety Policy Advisory Commission. In August 1994, the tsunami survey was mailed to school principals in 96 selected Oregon coastal schools in Clatsop, Coos, Curry, Douglas, Lane, Lincoln, and Tillmook Counties. Responses were received from 39 schools (41 percent).

Of the 39 coastal schools that responded, 16 stated that some form of tsunami preparedness is currently taught in all grades K–12 levels. Survey responses indicate that grades 6, 7, and 8 receive slightly less tsunami preparedness education than grades K–5 or 9–12.

Teaching methods and materials varied from school to school. Responses indicate that tsunami preparedness is generally taught during science class or in conjunction with earthquake preparedness education. Tsunami evacuation areas include "small hill away from the school," "next to the school," "in front (east) of the school," "up the mountain," or "to higher ground." Tillamook County has a county-wide warning system that is reviewed as part of the schools' preparedness training. Teaching materials include earth-science curriculum materials, building-safety plans, teacher-prepared materials, information obtained from the Red Cross and Oregon State University, a tsunami handout provided by Clatsop County, and local information received from emergency government agencies.

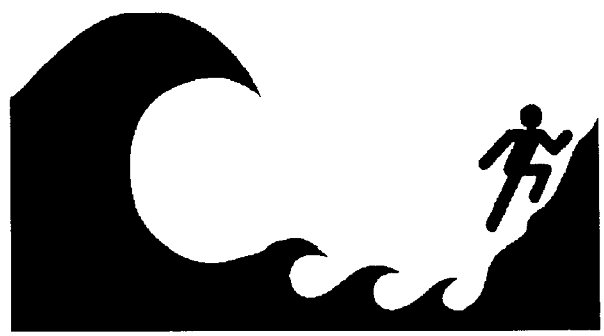
Schools were asked to list teaching materials that would be beneficial in relation to tsunami preparedness. Generally, schools suggested that any type of information on tsunami hazards would be beneficial for them as they prepare an education plan. Specific information on timing and alternative escape routes, off school property, was also suggested as beneficial.

Of the 39 schools that responded, only 15 practice tsunami evaculation drills during the school year. Seven of the schools conduct tsunami drills monthly, while other schools conduct drills bimonthly, two times a year, or yearly. Documentation of tsunami drills is maintained in 15 schools. Tsunami drills are being conducted at the same time as earthquake drills in 12 schools. Of those 12 schools, 8 evacuate to high ground or go to an inland location off the school grounds. Limited responses were received for questions relating to evacuation routes, evacuation drills, and differences between tsunami drills and earthquake drills.

A total of 19 schools expressed interest in receiving training on how to conduct a tsunami evacuation drill, and 17 schools were not interested in receiving training.

Schools were asked whether a local workshop on tsunami hazards for teachers would be beneficial. Fifteen schools were not interested in a local workshop on tsunami hazards. From the 13 schools where it was felt that a workshop would be beneficial, topics suggested included presentation of factual information on tsunami hazards, an overview of procedures for classroom instruction and evaluation drills, inland impacts, safety issues, and information on age-appropriate curriculum materials.

A copy of the tsunami survey results was requested by 22 schools. A complete set of survey responses will be maintained at the Portland office of the Oregon Department of Geology and Mineral Industries. For further information contact the Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street, Suite 965, Portland, Oregon 97232, phone 503-731-4100, FAX 503-731-4066. □



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GMS–83, 9 p., map scale 1:24,000.

———1994, Geologic map of the Remote quadrangle, Coos County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–84, 8 p., map scale 1:24,000.

Black, G.L., and Priest, G.R., 1993, Geologic map of the Camas Valley quadrangle, Douglas and Coos Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–76, 4 p., map scale 1:24,000.

Niem, A.R., Niem, W.A., and Baldwin, E.M., 1990, Geology and oil, gas, and coal resources, southern Tyee Basin, southern Coast Range, Oregon: Oregon Department of Geology and Mineral Industries Open-File Report O–89–3, 95 p., 3 plates.

Ryu, I.C., Niem, A.R.,and Niem, W.A., 1993, Schematic fence diagram of the southern Tyee Basin, Oregon Coast Range, showing stratigraphic relationships of exploration wells to surface measured sections: Oregon Department of Geology and Mineral Industries Oil and Gas Investigation 18, 48 p., 1 plate.

Wiley, T.J., and Black, G.L., 1994, Geologic map of the Tenmile quadrangle, Douglas County, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–86, 5 p., map scale 1:24,000.

Wiley, T.J., Priest, G.R., and Black, G.L., 1994, Geologic map of the Mount Gurney quadrangle, Douglas and Coos Counties, Oregon: Oregon Department of Geology and Mineral Industries Geological Map Series GMS–85, 5 p., map scale 1:24,000. □

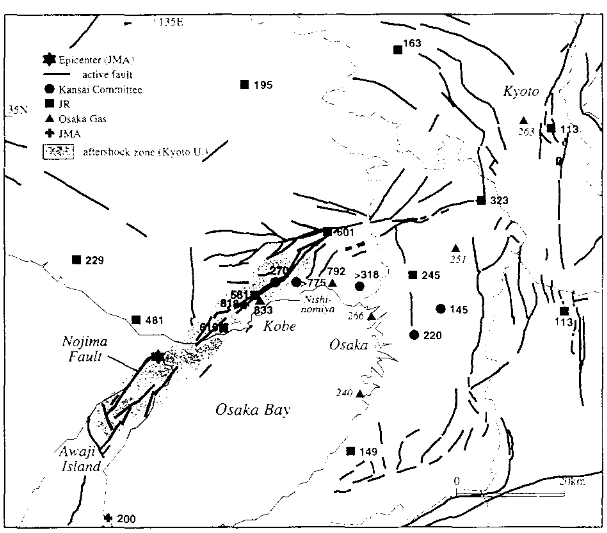
Some notes on the Kobe, Japan, earthquake of January 17, 1995

On January 17, 1995, a magnitude 6.9 (moment magnitude, M_W) earthquake struck Kobe, Japan, a port city on the Pacific shore of Japan's Honshu Island. The epicenter of the Kobe earthquake was located about 20 km (12 mi) southwest of downtown Kobe. The devastating ground shaking resulted in extensive loss of life and damage to property and disrupted commerce throughout the country. Ground accelerations due to shaking reached at least 0.8 *g*, which means that the forces of shaking were 80 percent of the force of gravity. What follows is a brief discussion of the earthquake effects, based on preliminary reports. In coming issues of *Oregon Geology*, more details of what is learned from this latest "urban earthquake" will be reported.

The Kobe earthquake resulted from a rupture of the northeast-southwest-oriented Nojima fault zone. The rupture began at a depth of about 10 km (6 mi). Approximately 30 to 50 km of the fault ruptured, producing 1–1.5 m (3–5 ft) of horizontal surface displacement. The sense of motion on the fault was right-lateral, strike-slip. This means that the west side of the fault moved 1–1.5 m to the northeast, compared to the east side. A duration of 10–12 seconds of strong ground shaking has been reported. These few seconds of shaking resulted in over 5,000 deaths and over 26,000 injuries, and approximately 300,000 people required shelter. All this happened in a city with a population of 1.5 million.

Western Japan lies on the Eurasian plate and has a historic record of moderate to large crustal earthquakes. Thanks to Japan's long historic record, it was known that Kobe had suffered large, damaging earthquakes in the past. However, damaging earthquakes have occurred much less frequently in the region of Kobe than in other parts of Japan. Consequently, some Japanese perceived the area as being immune to earthquakes, an attitude is not unlike that of comparing the Pacific Northwest to the San Francisco Bay area. Damage statistics are still being compiled, but it appears that over 100,000 buildings were destroyed or severely damaged. Reportedly, only 20 percent of Kobe's downtown buildings were usable following the earthquake. Estimates of the cost to rebuild have climbed to at least $100 billion, over five times the latest estimates for the magnitude-6.8 earthquake in Northridge, California, in 1994.

Damage to buildings, roads, railroads, ports, and pipelines resulted in loss of life and shelter and will continue to disrupt lives and commerce for many months to come. This damage and the difficulties Japan experienced in launching and carrying out emergency response measures following the earthquake highlight the importance of advance planning, preparation, and the mitigation of hazards. The port of Kobe, which reportedly supports 12–30 percent of Japan's exports, suffered damage to nearly all of its berths. Liquefaction of saturated, loose, silty soils was a major contributor to this and other damage. □



Map showing the area of Osaka Bay and Kobe, Japan; the location of the epicenter of the earthquake of January 17, 1995; the aftershock zone which gives some indication of the length of the fault rupture; locations of acceleration measurements; and the system of known faults in the area. Reproduced from EOS, v. 76, no. 6 (February 7, 1995), p. 49.

April is Earthquake Preparedness Month in Oregon

The saddening extent of suffering which the Kobe earthquake inflicted on the people in Japan also reminds us that we are not free from such disasters in Oregon—and not safer here than the people in San Francisco, either! Our scientists are working to give us more and more insight into earthquake phenomena, and even the Kobe earthquake will add to what we know about earthquakes and how to deal with them. Still, we cannot stop the mighty forces with which the Earth shapes and reshapes itself. However, we can **be prepared** to cope with them and their aftermath.

The Oregon Trail Chapter of the American Red Cross offers a pamphlet called "Before Disaster Strikes." It offers help in preparedness for home fires, severe winter weather, and floods on one page each; wildfires on two pages, but earthquakes on five!

Just a few leading questions may serve here to remind us that we should be ready to face events that could happen any time:

- How will our family reunite following a disaster?
- What can we do if the water supply is contaminated?
- If electricity is out, how will we get emergency information?
- Who will give first aid to my family if medical workers can't?

The pamphlet that answers these and many more questions can be obtained from the American Red Cross, P.O. Box 3200, 3131 N. Vancouver Ave., Portland, OR 97208-3200, phone 503-284-1234, extension 238. □

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*(**Margaret Steere**—continued from page 26)*

she returned to DOGAMI as a volunteer, she reorganized the photo file and brought it up to date and made an index of *Oregon Geology* articles from 1982 to the present. She then tackled learning to use a computer and entered over 700 titles of theses in the bibliographic database. Prior to her death, she was working on a way to enter data on site-specific reports into DOGAMI's bibliographic database.

She was a great friend to all of us at DOGAMI, and her skills, knowledge, quiet humor, and competency will be missed. She is survived by her nieces Lois Beattie of Portland and Alice Coulombe of Pasadena, California, a nephew, several cousins, and numerous friends. At her request, remembrances are to be sent to the Community Music Center in Portland or to the Library Fund of OMSI's Camp Hancock. □

Preliminary reconnaissance survey of Cascadia paleotsunami deposits in Yaquina Bay, Oregon

by Curt D. Peterson, Department of Geology, Portland State University, Portland, Oregon 97207-0751, and George R. Priest, Oregon Department of Geology and Mineral Industries, Portland, Oregon 97232

SUMMARY

Preliminary evidence of Cascadia paleotsunami deposits has been found in at least 14 latest Holocene marsh sites from the lower and middle reaches of Yaquina Bay. The near-field paleotsunami deposits are recognized as thin sand layers draped over paleomarsh surfaces that were buried by bay muds and peats. At least three events of Cascadia coastal subsidence and tsunami inundation are recorded in the lower Yaquina Bay marsh deposits.

The amount of coastal subsidence associated with paleotsunami deposition at the western end of the bay is small, e.g., 0–0.5 m for the last event and less than 1 m for the remaining two to three events. Subsidence is estimated from abrupt decreases in peat content, indicating subsidence to levels favoring fewer marsh plants than at intertidal-mud levels. The paleotsunami sands were recognized by their occurrence as discrete sand layers immediately atop peat-rich layers.

The 50:1 ratio of tidal versus river discharge in the estuary makes it unlikely that river flooding deposited sand sheets on the buried peats in the lower estuary. Paleotsunami sands show local variability in thickness (2–10 cm) and thin with distance above a bay constriction of the estuary about 9 km from the bay mouth. Paleotsunami sand deposits thicken at the terminal end of one large blind slough but thin with distance from the main channel in several other small embayments.

Evidence of paleotsunami deposition associated with the last Cascadia earthquake is found at least 14 km upriver from the mouth. The maximum distance of upriver inundation for this event has yet to be established. Geologic records of Cascadia tsunami deposition in the sinuous Yaquina Bay are best preserved in tidal-marsh settings within protected embayments branching off the main channel.

INTRODUCTION

An effort to warn the public about Cascadia tsunami hazards in Oregon has been initiated by a variety of county emergency managers, state agencies, and educational institutions. Part of this effort includes the placement of historical marker signs at strategic locations along the Oregon coast by the Oregon Department of Geology and Mineral Industries (DOGAMI) and the Oregon Travel Information Council. The first three signs were placed in Seaside, Newport, and Reedsport (Figure 1). The signs include maps of core-site locations, where Cascadia paleotsunami deposition is recorded in the adjacent bays.

Of the three localities selected, only Yaquina Bay had not previously been surveyed for paleotsunami deposition. By comparison, paleotsunami runup has been well documented in the Neawanna wetlands in Seaside (Darienzo, 1991; Peterson and others, 1993; Darienzo and others, 1994). Preliminary investigations of paleotsunami inundation have been conducted in the Umpqua estuary (Briggs and Peterson, 1992). The tsunami deposits there have been traced from Winchester Bay upriver to the Scholfield Slough near Reedsport (Briggs, 1994). Finally, latest Holocene paleoseismic events of coastal subsidence and associ-

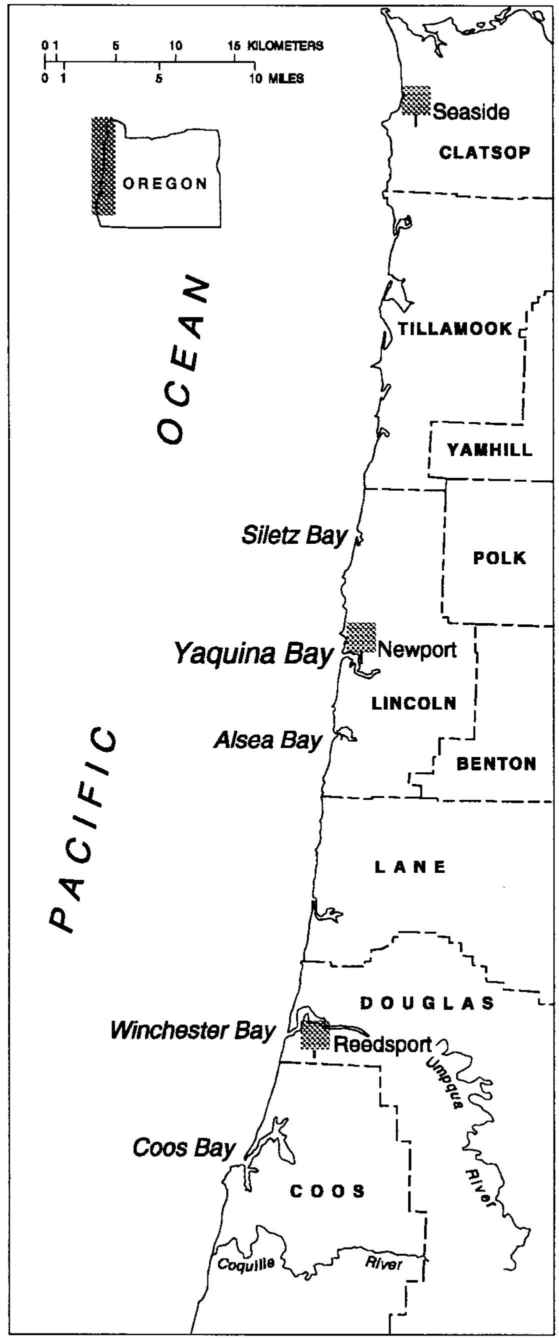

Figure 1. Map showing a portion of the Oregon coast and its counties and the locations of the study area (Yaquina Bay) and other river estuaries and bays discussed in this paper. Patterned squares indicate locations of tsunami information signs newly installed in Seaside, Newport, and Reedsport.

ated tsunami runup have been well documented in two bays immediately adjacent to Yaquina Bay, including Alsea Bay to the south (Peterson and Darienzo, 1991) and Siletz Bay to the north (Darienzo, 1991; Darienzo and others, 1994).

The primary objective of this study is to establish representative sites of paleotsunami deposition in Yaquina Bay. Specific wetland sites were selected for investigations of cutbanks or shallow gouge cores to establish the distribution of paleotsunami runup evidence in the bay. Two additional objectives include documenting tsunami propagation and deposition in a sinuous bay morphology and evaluating the preservation potential of tidal marsh sites that are sensitive to paleotsunami deposition.

The Yaquina Bay mouth has been significantly narrowed by jetty construction, which will possibly decrease future Cascadia tsunami runup in the bay. However, the paleotsunami evidence in Yaquina Bay is relevant to tsunami hazard planning in the Cascadia Subduction Zone (CSZ). It is relevant as a proxy warning about tsunami runup at all central Oregon beaches, bay mouths, and bay constrictions, where runup is likely to be amplified. Furthermore, the extensive development of the Yaquina Bay waterfront makes this locality an area of special concern with regard to tsunami evacuation planning. Finally, it is hoped that paleotsunami inundation data in Yaquina Bay can be compared to computer models of tsunami inundation in the bay, including pre-jetty and post-jetty conditions, to verify the accuracy of such runup models.

METHODS OF STUDY

Owing to limitations of time and budget, only a preliminary reconnaissance survey was completed. Tidal-marsh deposits in the lower reaches of Yaquina Bay were examined in June 1994 by analysis of cutbank gouge cores. This survey was performed to verify reported evidence of paleotsunami runup near the Hatfield Marine Science Center (Darienzo, 1991; Darienzo and others, 1994). We extended the survey area to the middle reaches of the estuary to establish whether paleotsunami inundation was recorded up the Yaquina River channel. We selected survey sites to cover as much of the bay as possible and to test various modes of paleotsunami sand deposition and preservation. Targeted sites included marshes near the bay mouth, along the length of a blind slough, at a major constriction in the lower bay, and at point bars of major channel bends in the middle bay.

Only shallow subsurface records (1–2 m below modern marsh tops) were examined for evidence of the last several paleotsunami events (expected ages of 300–1,500 years B.P.) in the central CSZ (Darienzo and others, 1994). Gouge cores were examined, photographed, and logged in the field. No subsampling was performed for either deposit mineralogy, grain-size analysis, microfossil paleotidal-level indicators, or event radiocarbon dating. Distinct events of paleosubsidence and/or paleotsunami deposition in Yaquina Bay are tentatively correlated to previously dated horizons in this and adjacent bays (Figure 2). However, additional radiocarbon dating of detrital organics in the paleotsunami deposits is required to confirm the tentative correlation of the paleoseismic events in the lower reaches of Yaquina Bay.

Coseismic subsidence events were recognized by the following criteria:

1. Abrupt decrease of organic content upward in the stratigraphic section, generally passing from an organic-rich peat to an organic-poor silty mud.
2. Persistent occurrence at the same depth (±5 cm) below the surface over a wide area.

Tsunami sands were recognized by the following criteria:

1. Sandy layer in sharp depositional contact with an underlying buried organic-rich soil and an overlying silty mud with much less organic content than the underlying soil.
2. Persistent occurrence at the same depth (±5 cm) below the surface over a wide area.
3. Thinning of the sand layer up the estuary in sites located nearest the main channel.
4. In some cases, thickening of the deposits toward the apex of V-shaped reentrants in the bay. An example is the King Slough area.
5. Lack of any other obvious mechanism for deposition of the sand layer.

The last criterion requires some explanation. The ratio of tidal to river discharge in the bay is on the order of 50:1 (Peterson and others, 1984), so there is little or no opportunity for river flooding to achieve the current velocities necessary to pick up and deposit sand layers at the sites sampled. Likewise, storm surges are unlikely to have enough energy to deposit sediment in high marsh sites, especially at distances in excess of 2 km inland, where most samples were taken. There is some uncertainty about this latter observation, since the bay was clearly more open to the sea before jetty construction, which allowed storm surges more access (Figure 3). However, criterion 1 makes river- or storm-surge depositions unlikely, since these phenomena should produce random occurrences of sand layers rather than consistent sequences of sand depositional events upon coseismic subsidence events, with no tidal-mud deposition intervening.

Finally, core sites thought to show unequivocal evidence of paleotsunami deposition were plotted on a base map for preparation of the tsunami sign for the Yaquina Bay area. These core sites represent known distances of paleotsunami inundation in Yaquina Bay. Maximum distances of recorded paleotsunami inundation in the middle reaches of Yaquina Bay have yet to be established.

RESULTS

Fourteen core sites were logged for stratigraphic evidence of coastal subsidence and/or paleotsunami deposition (Figure 3). These core logs (YB-1 to -14) and one log from previous work (HF 1–3; Darienzo, 1991) are shown in Figure 4. The depth sections are measured to the nearest 1 cm. The core tops are set at ground surface, which is estimated to be between 1 and 2 m above modern mean tidal level (MTL) for these marsh settings (Table 1). No anomalous sand layers or laminae were found in gouge cores of the uppermost 25 cm of marsh deposits, the interval that is thought to represent deposition during historic time. Historic events of catastrophic river flooding (100-year flood of 1964), storm surges (up to 1 m above predicted tide in the lower bay; Pittock and others, 1982), or distant far-field tsunamis (1964 Alaskan tsunami; Lander and others, 1993) are not recorded at any of the high-marsh core sites observed in lower or middle reaches of Yaquina Bay.

Two cores, one each from the lower bay (YB-9) and middle bay (YB-11), were taken to a subsurface depth of 2 m. These cores record the last four or five coastal subsidence events in Yaquina Bay as abrupt decreases in peat content upcore. Events 1, 2, and 4 in the two cores (YB-9 and -11) are associated with anomalous sandy layers, interpreted to be paleotsunami deposits. Event 3 is conspicuous in its lack of corresponding paleotsunami deposits in Yaquina Bay and in the two adjacent bays, Alsea and Siletz (Figure 2), as well as in other northern Oregon bays (Peterson and others, 1993). The last four subsidence events are assumed to cor-

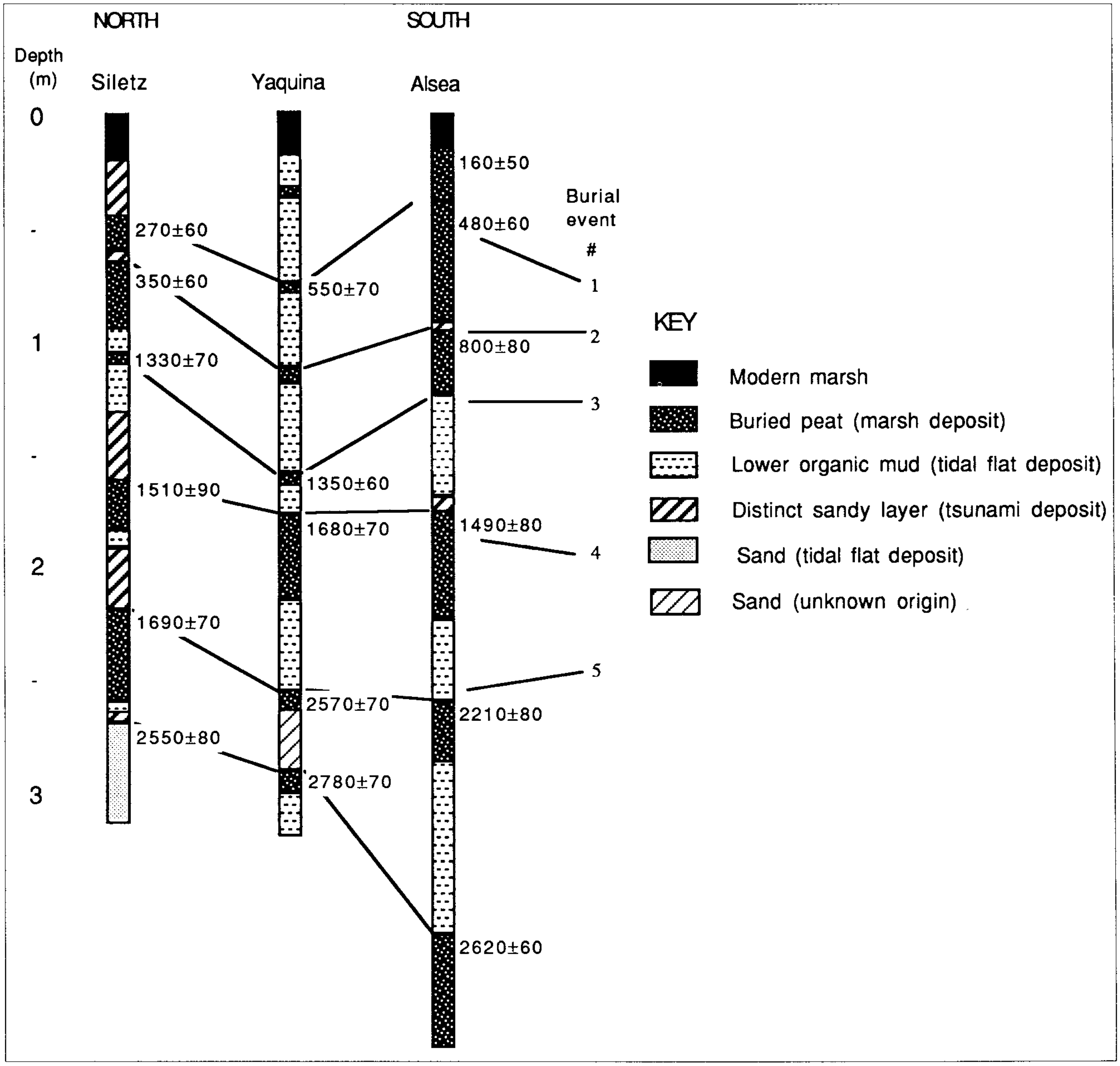

Figure 2. Generalized event stratigraphies from Alsea, Siletz, and Yaquina Bays. Radiocarbon dates are from buried peaty sections that likely predate the coastal subsidence events. Paleotsunami deposits are regionally associated with central Cascadia events 1, 2, and 4, but not 3. The second Cascadia subsidence (event 2) is not recorded at Siletz Bay. Assuming that coseismic subsidence occurs only above ruptured portions of the locked interface between the North American and subducting Juan de Fuca plates, this evidence suggests that the event 2 rupture included the Alsea and Yaquina Bays but did not extend as far north as Siletz Bay.

respond to the central CSZ subsidence events: Event 1 at 300 calibrated years before present, event 2 at ~800 radiocarbon years before present (RCYBP), event 3 at about 1,100 RCYBP, and event 4 at about 1,400 RCYBP (Peterson and others, 1993; Darienzo and others, 1994).

The two deeper cores (sites YB-9 and -11) might straddle the projection of a possible west-east trending fault reported to offset Quaternary marine terraces on opposite sides (north and south) of Yaquina Bay (Ticknor, 1993). The two core sites do not appear to show any significant stratigraphic differences for the last four subsidence events, either in terms of the number of events or the depths of event horizons. Subsidence events recorded in marshes of the middle and upper reaches of Yaquina Bay (Darienzo, 1991) have been tentatively correlated to central Cascadia dislocation events in northern Oregon (Darienzo and others, 1994). However, corresponding tsunami deposition with subsidence events had not been established for Yaquina Bay. The results shown here confirm that the subsidence events in Yaquina Bay are associated with paleotsunami deposition, linking them to regional dislocations of the Cascadia megathrust.

The remaining 13 cores sites were cored to subsurface depths of about 1 m. Five of these cores (YB-2, -4, -6, and -10; HF 1-3) contain sand-deposit records of two CSZ tsunamis, with another seven cores showing evidence of only one paleotsunami. The shallowest paleotsunami deposit in each core is presumed to represent the last Cascadia dislocation (event 1), based on (1) depth in core, and (2) lack of overlying subsidence sequences or, for the westernmost core sites, a lack of subsidence associated with the youngest paleotsunami event (see below). Additional radiocarbon dating is required to verify the presumed youngest ages for these shallowest paleotsunami deposits.

Several core sites that were located along the entrance shore-

Table 1. *Wetland settings, elevations, and peat abundance in central Oregon bays*[1]

Marsh settings in central Oregon bays	Elevation in meters above mean tidal level (MTL)	Percent peaty material (relative to core surface area; visual estimate)	Percent organics (weight fraction from loss on ignition—LOI)	Core log key
Forest/shrub	2.0±0.25	>80	>50	Peat
High marsh	1.5±0.25	50–80	20–50	Muddy peat
Transitional marsh	1.25±0.25	20–50	10–20	Peaty mud
Low marsh	0.75±0.25	5–20	5–10	Slightly peaty mud
Colonizing marsh / mud flat	0.5±0.25	1–5	<5	Rooted mud / mud

[1] There is significant overlap of marsh setting elevations shown in this regional compilation. Marsh settings at individual marsh sites typically show less variability in tidal elevation. The marsh settings, tidal elevations, percent peaty, and percent organics used in this table are compiled from data from several central Oregon bays including Yaquina Bay (Darienzo and Peterson, 1990; Darienzo, 1991; Peterson and Darienzo, 1992; Briggs, 1994).

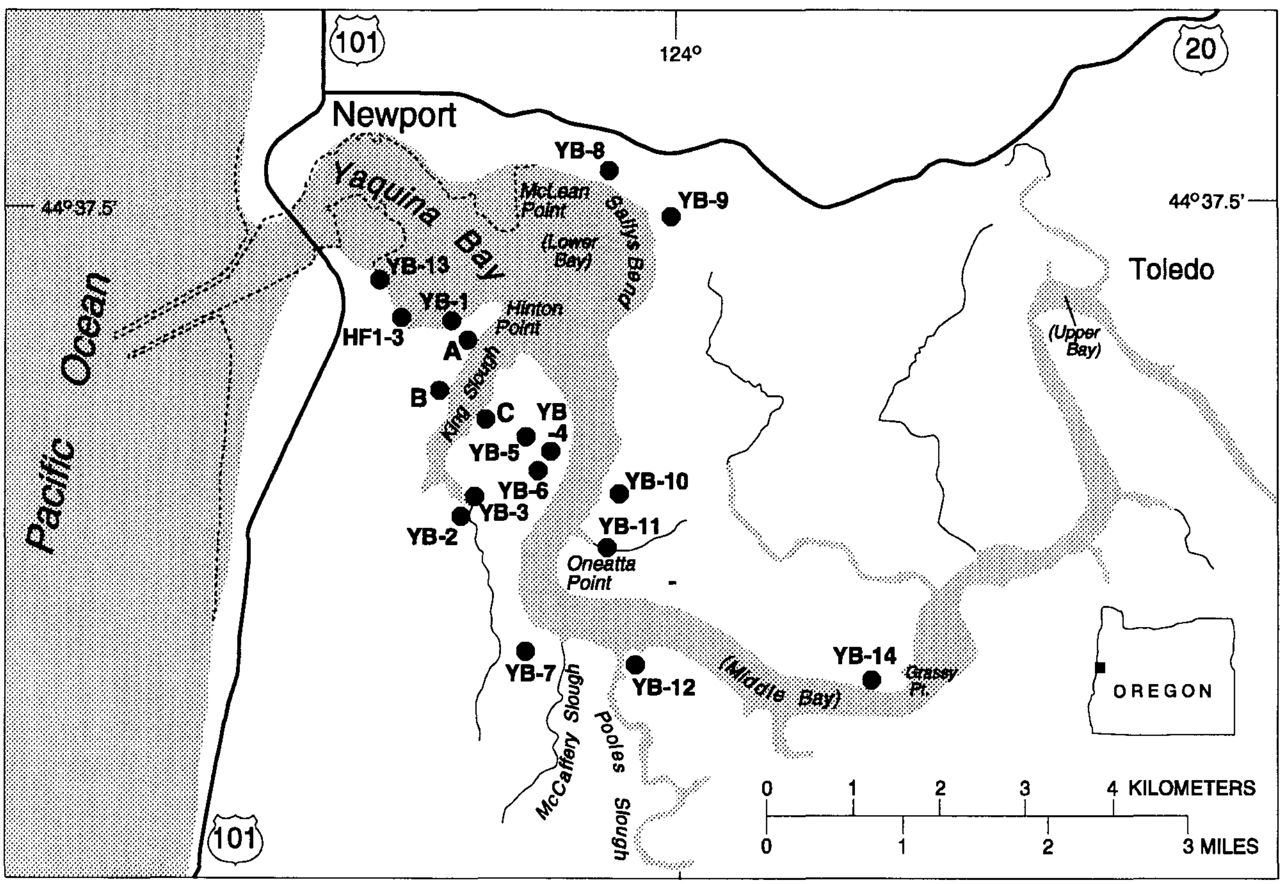

Figure 3. Bay morphology and core site locations in Yaquina Bay before jetty construction and fill changed the entrance to the bay (after U.S. Coast Survey, 1868); dotted lines indicate today's conditions. Core sites containing some evidence of paleotsunami deposition are numbered YB-1 to YB-14. The site of a previously cored marsh that contains paleotsunami sands (HF 1-3; Darienzo, 1991) is also shown. Several sites containing relatively deep marsh records but no paleotsunami sands (A, B, and C) are shown for Kings Slough. Sites cored along fringing marshes of the exposed bay shorelines and the Yaquina River channel that did not contain any evidence of any paleosubsidence events, i.e., abruptly subsided peats, are not included here.

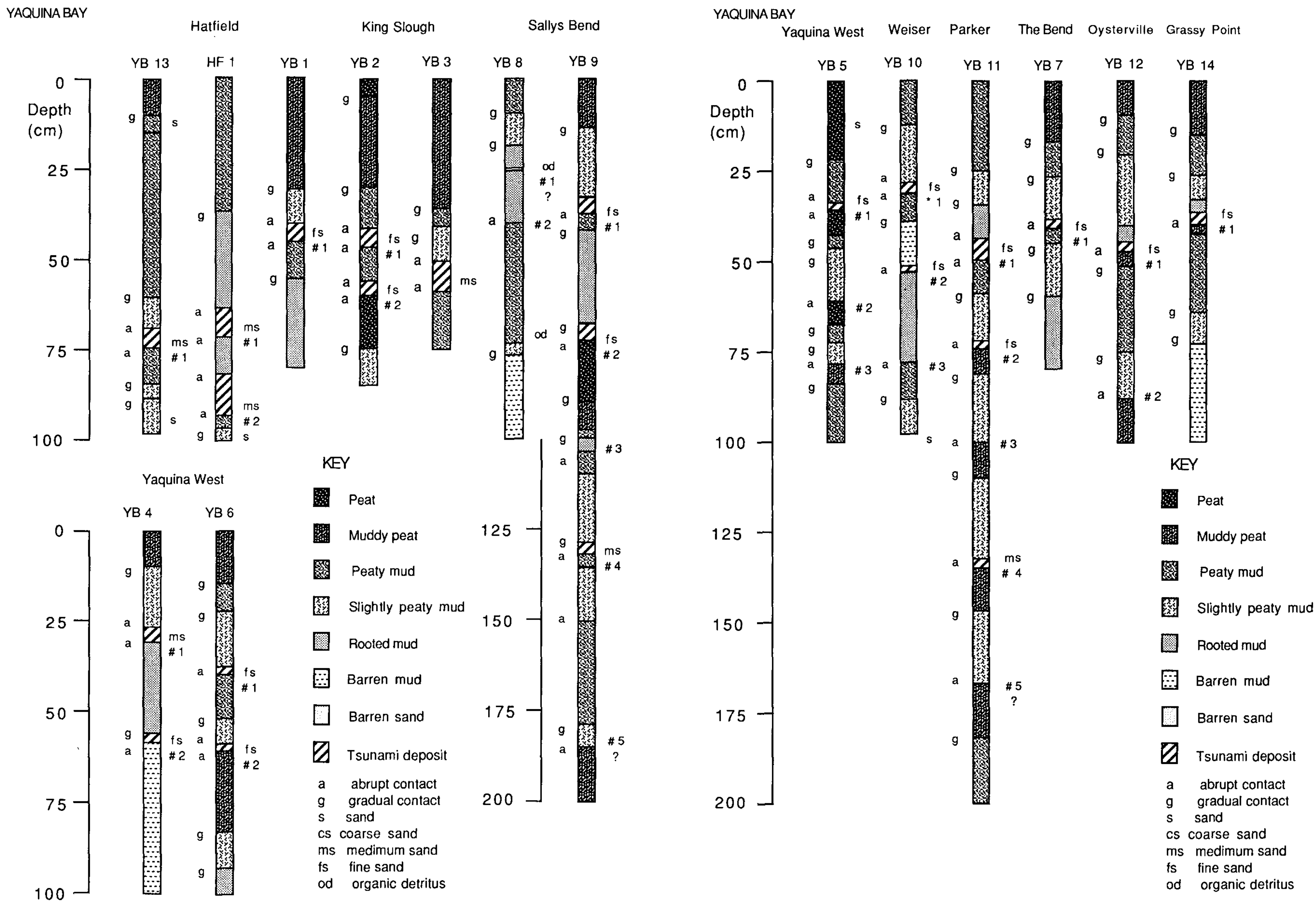

Figure 4. Core logs from 15 core sites in Yaquina Bay. Core site locations are shown in Figure 3. Mean grain-size estimates as recorded in logs are based on visual comparison with particle-diameter size cards: medium sand (0.25–0.50 mm), fine sand (0.125–0.25 mm), and very fine sand (0.062–0.125 mm). See Table 1 for paleotidal elevation interpretations of the core logs as based on relative peat abundance.

lines to King Slough did not show any evidence of tsunami deposition (YB-A, YB-B, and YB-C, Figure 3). One additional core site from the north side of the lower bay (YB-8) also failed to show evidence of tsunami sand deposition. An anomalous silty layer capped by detrital woody debris at about 30 cm of depth in YB-8 might represent a flooding event associated with the last Cascadia dislocation. The paleotsunami-deposit sands directly overlying the buried peaty horizons range from 2 to 10 cm in thickness and are dominated by fine sand-size fractions (Figure 4). Multiple cores or cutbank observations taken at each core site, within a radius of 5–10 m, show that the sand layers were deposited as thin sand sheets draping the wetland surfaces. Layering and/or fining-upward sequences were observed in some of the paleotsunami deposits, but they require coring at larger diameter for verification. The amount of coastal subsidence associated with the paleotsunami deposition is discussed below.

CSZ event 1 shows relatively little or no subsidence at the western end of Yaquina Bay in core sites YB-13, -1, -2, and -3 (Figure 4; Table 1). In the cores that lack intervening tsunami sands, the upper contacts between the buried peaty muds and the slightly peaty muds are gradational and at least several centimeters in thickness. By comparison, there is evidence of at least 0.5–1 m of coseismic subsidence associated with event 1 in the more landward core sites YB-11, -12, and -14 from the middle bay reaches. Furthermore, the upper contacts associated with this buried peaty horizon in the upper bay reaches, upstream of Toledo, are sharp (less than 1 cm in thickness), as described by Darienzo (1991). These relations suggest that the western end of Yaquina Bay might have been very near, or within, the zero-isobase zone for the last CSZ dislocation (event 1). (The zero isobase is the area between regions that subside and those that rise up during a great subduction zone earthquake. Zero-isobase position can shift from earthquake to earthquake, hence the term "zero-isobase zone.") By comparison, events 2, 3, and 4 do show significant coseismic subsidence (0.5–1 m) in the lower bay reaches, where their records are preserved. None of the subsidence events recorded in the lower reaches of Yaquina Bay show upcore transitions of forest to colonizing marsh or high marsh to barren mudflat (Figure 4). The lack of such transitions indicates that subsidence in the western parts of Yaquina Bay probably did not exceed 1 m for the last four Cascadia earthquakes (Table 1).

The second objective addressed in this reconnaissance survey is to gain a better understanding of tsunami propagation and deposition in a sinuous fold-belt bay. Little is known about Cascadia tsunami propagation and attenuation in sinuous bay morphologies. Yaquina Bay represents the northernmost coastal drainage to be influenced by coastal fold-belt tectonics (Peterson and Briggs, 1992). Sinuous bay morphologies of the Umpqua, Coos, and Coquille Rivers more strongly reflect the roughly north-south striking structures of the south-central Oregon coast. However, these bays are apparently located over the zero-isobase zone (Briggs, 1994). As a result, they lack consistent subsidence records by which to help identify Cascadia tsunami deposits. Several critical conditions are necessary for the resuspension, transport, and deposition of sand by tsunami surges. The most important factors are sediment supply and grain size, surge velocity, turbulence, and bottom roughness. In addition, deposits must escape postdepositional erosion by subsequent tsunami surges, tides, storm surges, and tidal or estuary channel migration. These conditions are likely to vary greatly with location along meandering channels and blind sloughs of the sinuous bays. Yaquina Bay offers an opportunity to test some basic assumptions about tsunami deposition in these sinuous bay settings. For instance, does a constriction in the estuary create high enough current velocity to neutralize the continuously falling velocity of the tsunami as it dissipates inland? Do blind sloughs create a thickened deposit at their apex from piling up of water and suspended sediment?

In order to establish the potential spatial variability of tsunami deposition in Yaquina Bay, several paired or clustered core sites were examined for paleotsunami sand thickness. Specifically, paired sites were cored at YB-13 and -1 and at YB-8 and -9 to test for surge directionality inside the bay mouth (Figure 3). Clustered sites, including A, B, C, YB-2, and -3 were examined in King Slough, a blind slough that ends in a terminal marsh at its southern end. Another cluster of sites, YB-4, -5, -6, -10, and -11, was examined in the area of bay constriction, between Yaquina and Oneatta Point, that separates the lower and middle bay reaches. Finally, several sites (YB 7, 12, and 14) were cored at channel meander bends of the middle bay.

The lower bay marsh sites (YB-13, -1, and -9 and HF 1–3) show relatively similar thicknesses of paleotsunami sands (Figure 4). Assuming that, for a restricted area, deposit thickness corresponds in some way to current velocity, paleotsunami propagation was apparently very effective in "turning the corner" south of the paleotidal inlet (Figure 5). The event 1 layer thins with distance to the west of site YB-13 (reconnaissance gouge coring transect not shown), indicating that this marine surge probably propagated inshore via the paleotidal inlet rather than over the spit. A minor topographic depression at site HF 1–3 might account for the slightly thicker event 1 tsunami sand layer there, relative to the adjacent high-marsh sites at YB-13 and -1. More importantly, YB-8 north of Sallys Bend contains little or no evidence of paleotsunami sand deposition. This was unexpected because YB-8 is only a short distance (about 500 m) from well-developed paleotsunami deposits at a similarly exposed site (YB-9, Figure 3). These results demonstrate the local variability of tsunami sand deposition, likely the result of differences in available sand supply and/or surge hydrodynamics. Computer modeling of tsunami inundation together with additional close-spaced coring of the bay marshes is required to better understand the local variability of tsunami deposits in the lower reaches of Yaquina Bay.

In King Slough several sites (A, B, C) were cored in fringing marshes along the entrance shorelines to the slough (Figure 3). None of the three sites contained discreet sand layers within the peaty sections. The ages of two sites (A and C) were not well constrained due to the lack of an obvious subsidence event recorded in the peaty muds, about 1 m thick at each site. By comparison, site B did show an apparent subsidence event, likely to be event 2, at about 70 cm depth (not shown in core logs). In contrast to the lack of paleotsunami deposition recorded in the fringing marsh sites of King Slough, the terminal marsh area (sites YB-2 and -3) did show consistently thick paleotsunami deposits. The paleotsunami sand deposit in site YB-3 (possibly event 1) is nearly 10 cm in thickness. One interpretation of these results is that a surge "funneling effect" in King Slough amplified runup height at the terminal marsh sites, leaving anomalously thick deposits there (Figure 5). Alternatively, greater surge turbulence along the entrance shorelines might have precluded sand deposition in these more exposed sites. In any case, the best developed and/or preserved paleotsunami deposits occurred at the terminal end of the blind slough.

There is some evidence of sand layer thinning with distance (about 100 m) from the main channel (sites YB-4 to -6) in a small embayment just below the bay constriction (Figures 3 and 4).

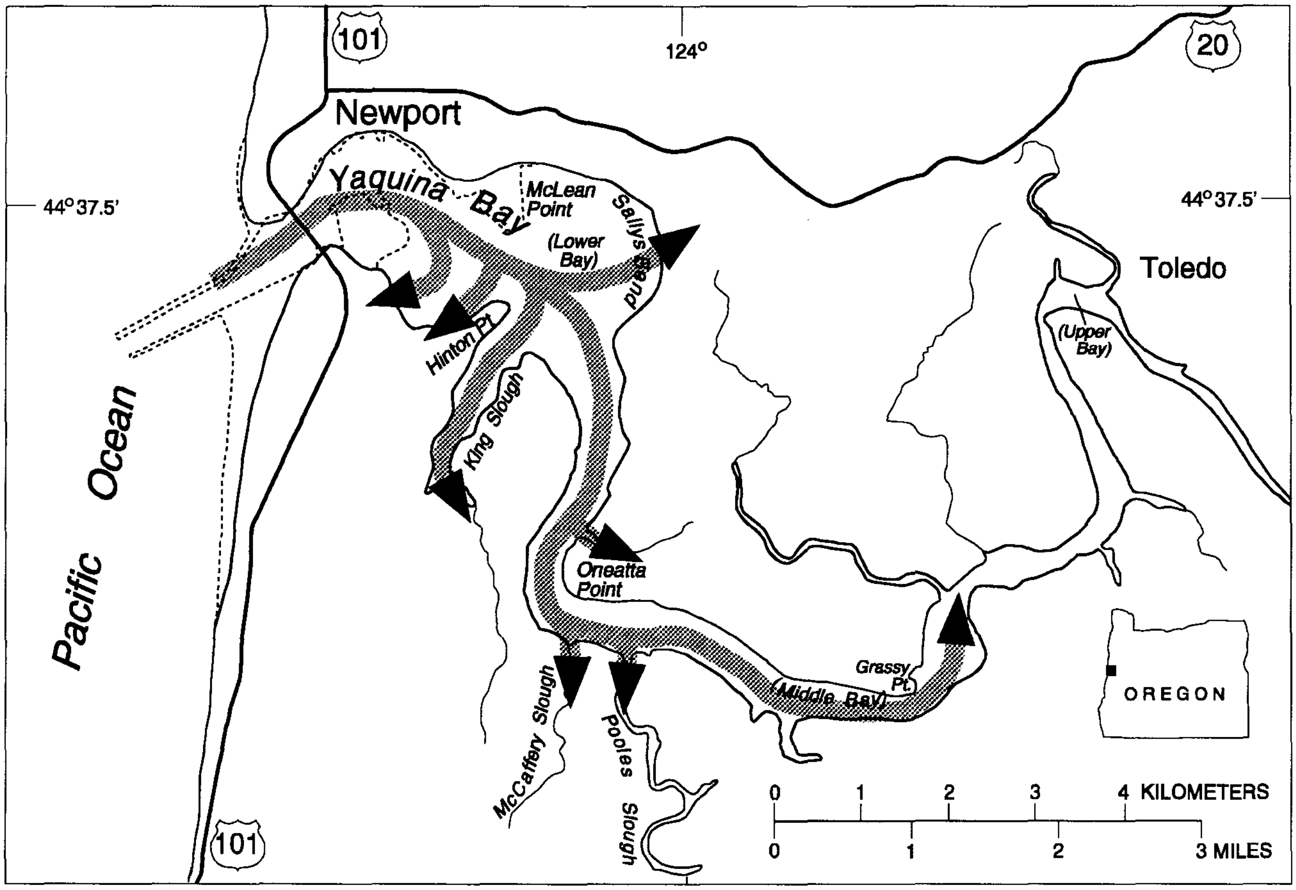

Figure 5. Map of paleotsunami surge propagation in Yaquina Bay based on evidence of tsunami deposition associated with the last Cascadia dislocation (event 1). Bold lines show the 1868 shoreline as in Figure 3. This shoreline is probably similar to the shoreline when the last tsunami struck about 300 years ago. Arrows show assumed surge paths based on shortest distances to inundated marsh sites. The paleotsunami inundation shown here represents only the minimum "known" distance of Cascadia tsunami flooding. Maximum distances of Cascadia tsunami inundation recorded in geologic deposits or estimated from numerical modeling have yet to be established for Yaquina Bay.

However, paleotsunami sand deposition is well recorded for events 1, 2, and 3 at several hundred meters distance off the main channel in Parker Slough (site YB-11). Both sites YB-10 and -11 are located in small blind sloughs in the narrowest area of the bay constriction, between Yaquina and Oneatta Point. The bay marshes and tributary sloughs widen just above Oneatta Point. Paleotsunami deposits were not well developed off the main channel in the embayments at McCaffery Slough and Poole Slough. For example, the event-1 paleotsunami sand sheet pinches out just several tens of meters south of YB-7. Extensive coring did not yield any evidence of event-2 paleotsunami sands in the vicinity of YB-12, and only very-fine sand was found in the event-1 tsunami deposit. These results suggest some tsunami surge choking in the area of bay constriction. Further upstream, the attenuation of the event-1 surge(s) is demonstrated by narrowly localized sand deposition at YB-14, which reached only the outer edge of the point bar marsh at Grassy Point (Figure 5). The maximum distance of paleotsunami sand deposition recorded for the last Cascadia earthquakes has not been established in Yaquina Bay. However, possible evidence of paleotsunami deposition from earlier Cascadia earthquakes was found in marsh sites adjacent to the Yaquina River just above Toledo (Darienzo, 1991).

The third objective of this study is to add to our growing knowledge of the long-term preservation potential of tsunami deposit sites. Tsunami deposits are initially preserved in protected wetlands and supratidal and pond sites, where sediment resuspension and bioturbation are minimized. However, little is known about the long-term (hundreds to thousands of years) preservation potential of such sites in active-margin bays. These wetland sites and their paleoseismic stratigraphic records can be lost or altered by a variety of processes. Such processes include erosion by lateral channel migrations, wind-wave erosion of bay shorelines, and burial by debris flows or encroaching eolian-dune fields. The preservation potentials of tsunami record sites are likely to vary between bays as functions of their relative size, tidal:fluvial discharge ratios, and strain cycles of uplift and subsidence. Yaquina Bay provides intermediate conditions for all three variables relative to other bays in the central CSZ (Peterson and others, 1984; Darienzo and others, 1994).

Fringing marshes of the lower bay shorelines were found to have very young histories, recording only the last, or none, of the central CSZ subsidence events. These marshes have prograded over tidal flats that are particularly susceptible to wind-wave erosion. Wind-wave erosion is likely to be enhanced following coseismic subsidence events. Following such events the relative sea-level rise can increase wave fetch in the lower bay reaches, thereby increasing wave attack on exposed bay shorelines. Longer marsh records are limited to small tidal-creek marshes that are protected in embayments set back from the exposed bay shorelines (YB-8 and -9) or in terminal marshes of the larger blind sloughs (YB-3 and -4). Similarly, fringing marshes along the main channel of the middle bay generally contained very young peaty sections, typically younger than the last CSZ event (event 1; field evidence not shown). Presumably, lateral channel migrations in the narrow bay constrictions have episodically eroded marsh deposits back to the ancestral valley walls. One important exception is the Grassy Point marsh developed on a large point bar (Figure 3). Two subsidence events, probably central CSZ events 1 and 2, are recorded near the back (hillside edge) of this marsh. However, only subsidence event 1 was found preserved near the marsh-channel edge, where paleotsunami runup and/or sand supply was sufficient to deposit a distinctive tsunami sand layer. In summary, the short stratigraphic records of young fringing marshes tend to disfavor the preservation of paleotsunami runup evidence near exposed bay shorelines and upriver channel margins.

CONCLUSIONS

Reconnaissance coring in the lower and middle reaches of Yaquina Bay demonstrates widespread paleotsunami deposition in this tidal basin. Paleotsunami inundation is evident for three of the last four central CSZ dislocation events in latest Holocene time. The thicknesses of the paleotsunami deposits differ greatly between some of the core sites, presumably due to variation in local sand supply and/or surge hydrodynamics. However, there is a general trend of decreasing tsunami deposit thickness with distance upriver, particularly above the bay constriction at Oneatta Point. The furthest upstream evidence of paleotsunami deposition on a paleomarsh surface is located at Grassy Point about 14 km upriver of the bay mouth. This deposit lies atop a peaty soil buried as a result of coseismic subsidence during the last great Cascadia earthquake (event 1). Low preservation potential of fringing marshes along the exposed shorelines of the lower bay and the main channel meanders requires that coring for older paleotsunami runup records be performed in small embayments off the main channels.

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SSA calls to annual meeting in El Paso

The 1995 meeting of the Seismological Society of America (SSA) will take place March 22 through March 24 in El Paso, Texas, on the campus of the University of Texas. Seismologists, geologists, engineers, and educators from around the world will present their recent findings.

The program will include, among many other presentations and events, sessions on the following topics:

- Preliminary findings on the 1995 Kobe, Japan, earthquake.
- Microearthquake behavior in incipient rupture zones. Large earthquakes are sometimes preceded by an increasing number of small earthquakes. Data that are being collected at the monitoring experiment at Parkfield, California, will be presented.
- Seismology in K–12 education. Presentations will focus on using seismology as a thematic tool in science education as well as for increasing earthquake awareness and preparedness.
- Volcanic seismology. This session will focus on the relationship between seismic activity and volcanic activity, including findings related to the December 1994 eruption of the Popocatepetl volcano.

Further information is available from Nancy Sauer, RDD Consultants, Inc., 1163 Franklin Avenue, Louisville CO 80027, phone (303) 665-9423, FAX (303) 665-9413 (9 a.m. to 5 p.m. MST), and E-mail nksauer@dash.com.

—SSA news release

BLM and cavers join forces in Medford

The U.S. Bureau of Land Management in Oregon's Medford District has signed a Memorandum of Understanding with the Southern Oregon Grotto of the National Speleological Society for joining efforts to manage the caves on BLM land. BLM has recently acquired a significant cave (No Name Cave) and hopes to add Marble Mountain Cave. The cavers will assist BLM as volunteers in cave monitoring, exploration surveying, mapping and other efforts to manage caves as natural resources. □

Yes, we had bananas

by Steven R. Manchester, Department of Natural Sciences, Florida Museum of Natural History, University of Florida, Gainesville, Florida 32611-2035

ABSTRACT

A fossil banana has been recovered from the middle Eocene Clarno Formation, Wheeler County, Oregon. The fruit is preserved as an impression in lacustrine shale from the West Branch Creek assemblage. It is 4 cm long, 1.5 cm wide, and slightly curved and has well-defined longitudinal and transverse striations. Three rows of about ten seeds are evident, and these seeds correspond in external form to permineralized seeds that occur elsewhere in the Clarno Formation. The new information from fruit morphology, together with previous investigations of seed structure, indicate that the Clarno banana belongs to *Ensete*, a genus that is native to the Old World tropics today. The presence of this and many other tropical to subtropical fruits in the Clarno Formation indicates that Oregon experienced a warm, humid climate about 43 million years ago.

INTRODUCTION

The Eocene Clarno Formation of north-central Oregon contains one of the richest fossil fruit and seed assemblages in North America, with more than 170 species described from a single locality (Scott, 1954; Manchester, 1994). Some of the fruits have wings, indicating that they were adapted for dispersal by wind, while others were nuts and berries evidently eaten and dispersed by birds and mammals. Many of the Clarno fruit and seed genera are extinct, but at least a fourth of them belong to genera that are still living today (Manchester, 1994). Although the Clarno Formation predates the appearance of humans by about 40 million years, some of the Clarno fruits represent genera that have been brought into human cultivation during recent millennia. Clarno fruits that would be familiar to the modern human palate include walnuts (*Juglans clarnensis*), cherries (*Prunus olsonii*, *P. weinsteinii*), grapes (*Vitis tiffneyi*, *V. magnisperma*), kiwi (*Actinidia oregonensis*), and bananas (*Ensete oregonense*). Usually all that remains of these fruits in the fossil state are the hard parts, such as the seed or pit, but details of internal structure are often so well preserved that they may be identified through careful comparison with modern examples.

The presence of bananas in the Clarno Formation was recently determined on the basis of seeds showing internal morphology identical to that of extant *Ensete* (Manchester and Kress, 1993; Manchester, 1994). Modern bananas (Musaceae family) belong to three genera: *Musa*, *Ensete*, *Musella*. Although the familiar table banana (*Musa acuminata*) has been bred for small, infertile seeds and is grown from cuttings, wild bananas have hard seeds with distinctive morphology. Comparison of fossil seeds from the Clarno Nut Beds with those of modern Musaceae enabled Manchester and Kress (1993) to identify the Clarno banana as a representative of *Ensete* (Manchester and Kress, 1993). However, remains of the fruit itself were not known. The recent recognition of a complete banana fruit impression corroborates the determination from seeds and is presented for the first time in this article.

GEOLOGIC OCCURRENCE

The banana fruit and seed fossils occur in the Clarno Forma-

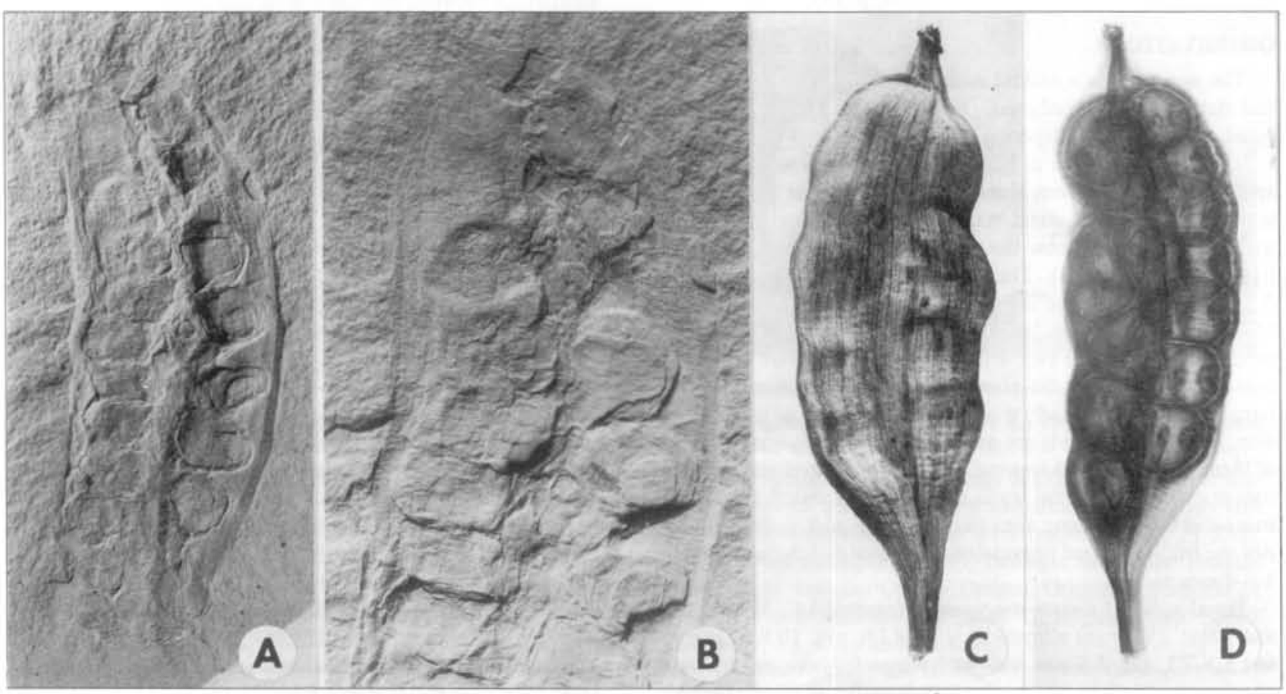

Figure 1. Fossil and modern fruits of the genus Ensete. *A.* Ensete *sp. fruit impression in shale (UF 15072), x2. B. Detail of same, showing longitudinal and horizontal striations of the fruit wall and shapes of the seed impressions, x3. C. Fruit of the living species,* Ensete calosperma *(New Guinea, coll. L.J. Brass 32476), x1. D. Same specimen as in C, X-rayed to show arrangement of seeds inside, x1.*

tion in Wheeler County, Oregon. The Clarno Formation includes volcanic flows, intrusions, lahars, and tuffs and is mostly middle to late Eocene in age (55–40 million years; Walker and Robinson, 1990; Suayah, 1990). At many locations, the tuffs yield well-preserved fossil plants (Hergert, 1961; Manchester, 1986, p. 224; 1994, p. 10).

The banana fruit impression was collected from lacustrine shales exposed in "Alex Canyon," a tributary of West Branch Bridge Creek about 6 mi west of Mitchell, Oregon (UF loc. 229c; SE¼ sec. 25, T. 11 S., R. 20 E.). This site carries the informal name "Alex Canyon," referring to Alexander Atkins, who first called my attention to the occurrence of fossil leaves at this site in 1981. The locality is on privately held land, and permission to collect was obtained at that time from the owner. Fossil leaves, winged fruits, and disarticulated fish remains are similar to those accessible to the public along road cuts of Highway 26 near the Ochoco divide (Cavender, 1968; Retallack, 1991). The West Branch Bridge Creek shales are known mostly for fossil leaves (Hergert, 1961; Manchester, 1986), but winged fruits (Manchester, 1991) and occasional flowers (Manchester, 1986, 1992) are also found. Based upon floristic comparisons with radiometrically dated Clarno deposits in the Cherry Creek drainage, the age of these sediments is probably within the range of 43–46 million years (Manchester, 1990).

The silicified seeds of *Ensete oregonensis* were recovered from the Nut Beds locality on the western edge of the Clarno Unit of the John Day Fossil Beds National Monument, about 20 km west of Fossil, Oregon (UF loc. 225; Manchester, 1981, 1994). Most of the specimens were collected by the late Thomas J. Bones, whose diverse collection forms the basis of a monographic treatment of the flora (Manchester 1994). This locality is middle Eocene in age, based upon the Bridgerian vertebrate fauna (Stirton, 1944; Hanson, 1973) and radiometric dates of 43–44 million years (Vance, 1988; Turrin *in* Manchester, 1994, p. 13).

OBSERVATIONS

The specimen is a natural mold of a banana that was buried and flattened in the sediment (Figure 1A,B). The fruit is elongated, slightly curved, tapering toward both ends, 4 cm long, and 1.5 cm wide. The apex is bluntly rounded; the base is torn but appears also to have been bluntly rounded; however, it is not certain if there was a distinct stalk. Well-defined lengthwise and transverse striations show the position of fibrous bundles in the fruit wall (Figure 1B). The longitudinal striations are about 0.5–0.8 mm apart; the horizontal ones more closely spaced, 0.3–0.5 mm apart. Two longitudinal rows of ten seeds each are clearly visible (Figure 1A); a third row of seeds with their long axes perpendicular to the plane of the compression may be inferred from the irregularly thickened middle zone of the impression. Although the seeds are not well preserved, the impressions of them indicate that they were more or less barrel shaped with convex-cylindrical lateral walls and bluntly rounded apices and bases and that their long axes were perpendicular to the long axisof the fruit. The seed impressions are about 5–5.5 mm long and 3.5–4 mm wide).

Fossil seeds of *Ensete oregonense* (Figure 2A-C; Manchester and Kress, 1993) are ellipsoidal, 10.0–12.0, avg. 10.8 mm long, and 5.3–7.2, avg. 5.8 mm wide with a rounded base and truncate attachment end; they are circular to subangular in transverse section. The seeds are smooth to finely striate longitudinally (Figure 2A, C). At the attachment end they have a wide depression with a rim about 1 mm high and a central plug about 1.2 mm in diameter. Longitudinal sections (e.g, Figure 2B) reveal a large, barrel-shaped central chamber (containing the embryo and endosperm) that is separated by a partition from a small chalazal chamber at the distal end; the embryo (preserved in only a few specimens) ascends into the central chamber from the attachment end of the seed and is 2.5 mm long, straight, and bulbous.

DISCUSSION

Based upon similarities of external form, a modern fruit of *Ensete calosperma* was selected for detailed comparison with the fossil and was X-rayed (Fig. 1C,D) to show the arrangement and shape of seeds. Although the modern fruit and its seeds are about twice as large as the fossil, the morphology is very similar. The modern specimen has three rows of seeds, and they are shaped and oriented similar to the seed impressions of the fossil. Two sets of striations, some running lengthwise and others running transversely, are characteristic of bananas. Fruits of extant *Musa* species usually have six or more rows of many seeds, and the presence of just three rows of seeds in the Clarno fossil supports the determination as *Ensete*.

The fossil fruit is small in relation to living species of *Musa* and *Ensete*. Note that the fossil specimen magnified two times in Figure 1A matches the natural size of the modern fruit in Figure 1C. Nevertheless, the fossil conforms in shape—including the slight curvature of the long axis and the length/width ratio—and in structural details—including both longitudinal and horizontal striations and more or less barrel-shaped seeds attached toward the central axis of the fruit (axile placentation).

The beautifully preserved silicified seeds of *Ensete oregonensis* from the Clarno Nut Beds locality (Figure 2A-C) have already been described and illustrated in more detail elsewhere (Manchester and Kress, 1993; Manchester, 1994). These studies indicate that the seeds represent *Ensete* and not *Musa*. The close similarities between the fossil seed and modern seeds of *Ensete* are readily apparent from a comparison of longitudinal sections (Figures 2A and 2D).

It should be noted that the seed impressions of the fossil fruit from West Branch Bridge Creek (Fig. 1A,B) are about half the size of seeds from the Nut Beds (10.0–12.0, avg. 10.8 mm long, 5.3–7.2, avg. 5.8 mm wide vs. 5–5.5 mm long, 3.5–4 mm wide). This size discrepancy may be significant, because more than 70 seeds from the Nut Beds were studied, and none were small enough to fall in the range of those in the fossil fruit. It may be that this particular fruit was immature, although the seeds appear to have been fully hardened. Possibly, the different modes of fossilization may have resulted in shrinkage of seeds in the impression fossil vs. swelling of the permineralized seeds. Taking the size differences at face value would suggest that the fruit specimen represents a different species, distinct from the one represented by the isolated seeds. With only one specimen of the fruit, however, I hesitate to establish a new species.

CONCLUSIONS

Ensete is a genus of seven species native today to the Old World tropics. The presence of this and many other tropical to subtropical fruits in the Clarno Formation indicates that Oregon experienced a warm, humid climate about 43 million years ago. The Clarno flora also contains many genera common to temperate areas today, yet the evidence from frost-intolerant plants such as bananas, palms, and cycads, together with the occurrence of crocodilian remains attests to a climate that was significantly warmer than that of today (Manchester, 1994). This information

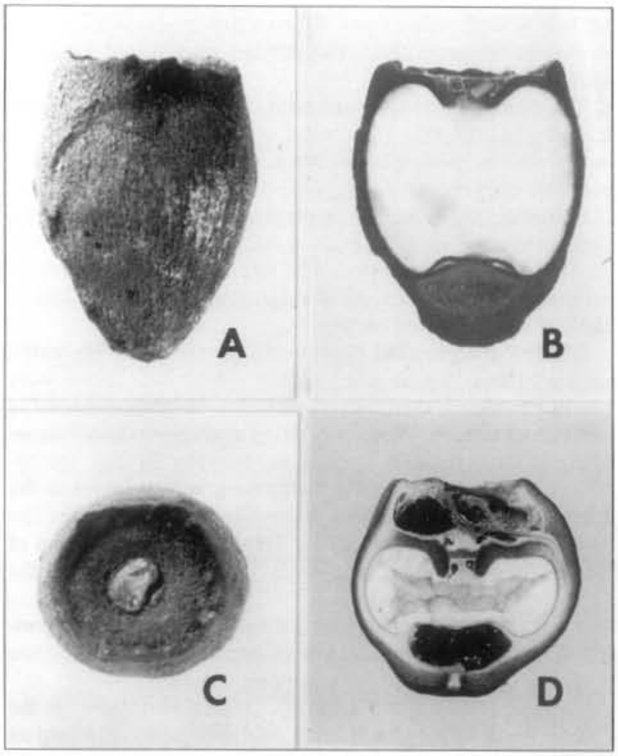

Figure 2. Fossil and modern seeds of Ensete. *A-C. The fossil species* Ensete oregonense *from Clarno Nut Beds locality, x5. A. Lateral view showing striate seed coat and apical truncation from which the operculum has detached (holotype, UF 6621). B. Same specimen, sectioned longitudinally showing silica-filled central endosperm chamber. C. Apical view of the specimen from A, prior to sectioning. D. Modern* Ensete glaucum, *sectioned longitudinally for comparison with the fossil seeds (New Guinea, coll. Kress 83-1554), x3.*

is in accord with evidence from many other quarters, indicating that global climate was significantly warmer in the Eocene than at any time later (e.g., Wolfe, 1994).

The occurrence of *Ensete* in the fossil record of North America also is biogeographically significant, because *Ensete* grows natively today in Africa and Asia but not in the Americas. The Oregon record shows that the genus was formerly more widely distributed. The occurrence of this *Ensete* today in southeast Asia fits a pattern observed for other Clarno fossil plants as well. Among the modern genera identified from the Nut Beds assemblage (Manchester, 1994), 37 (or 90 percent) occur today in southeast Asia. This percentage is higher than that for other regions and is taken as an indication that southeast Asia served as a refugium for once-widespread thermophilic genera that could not withstand the effects of climatic cooling later in the Tertiary and during the Quaternary.

ACKNOWLEDGMENTS

The banana specimen was collected and donated by Ian Gordon in 1983, and it lingered in storage, unidentified until recently. Modern fruits for comparison were provided by W.J. Kress. Permission to collect at the West Branch Bridge Creek locality was kindly granted at that time by Mr. Wilson. X-radiographs were prepared with equipment at the C.A. Pound Laboratory, University of Florida. This project was supported in part by grants DEB-81-11-89, EAR-8707523, and EAR-8904234 from the National Science Foundation. This paper represents number 456 in *Florida Contributions to Paleontology*.

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California now certifies hydrogeologists

Effective August 17, 1994, all qualified registered geologists in California who want to become "Certified Hydrogeologists" may take the hydrogeology examination scheduled for Sacramento and Riverside March 28 or October 3, 1995, or every six months thereafter. Final filing date for the October 1995 exam is July 7.

For qualifications or other information, contact the address below. If you are qualified and interested in taking the exam, you may ask for the examination packet: State Board of Registration for Geologists and Geophysicists, 400 R Street, Suite 4060, Sacramento, CA 95814, phone (916) 445-1920, FAX (916) 445-8859. □

Gold dredges in the Sumpter Valley

by Bert Webber, Research Photojournalist, P.O. Box 11, Medford, OR 97501

That antique gold dredge sitting in its pond at Sumpter, Oregon, resembles a dilapidated and abandoned five-story hotel. But it was not always that way. This Yuba-type dredge started life in 1935, was forced to shut down during World War II, then resumed churning the soil in the Sumpter Valley until August 1954.

In the history of dredging for gold, the Sumpter Dredge was not the largest, but it was certainly at the "large" end for size, on a list of dredges. It is 120 ft long and 52 ft wide. Its overall length, with its stacker, makes this engineering contraption 216 ft long.

The Sumpter Dredge worked as many as 23 men but not all of them at any one time. A large crew was necessary as the dredge worked 24 hours a day and nearly seven days a week. The time off line was for knockdown of the jigs and sluices once a week to remove the gold.

The gold dredge, also called a "dredger," is a weird-appearing apparatus that some claim resembles a giant praying mantis. It creaks, clatters, and emits horrendous groans and screams as it digs rocks and sand from the bottom of a river or pond. After digesting this muck in its bowels, it keeps what it seeks, gold, then spews the residue out its back side leaving mountains of rocks.

As to the potential effectiveness of dredging, which is a method of operating a large number of sluice boxes at one time, the *Encyclopedia Britannica* declared its sluice "considered to be the best contrivance for washing gold gravels."

The gold dredge is indeed a complicated system of motors and/or engines, winches, miles of cable, hydraulically operated devices, sluice boxes, quicksilver recovery units, shaking jigs, water pumps, sand- and water-discharge plumbing, and a conveyor stacker that dumps the leftovers far out behind the dredge.

Although some early dredges worked in rivers, most worked in their own ponds. When a dredge-master decided to change digging sites, the dredge moved and took its pond with it.

The Sumpter Dredge pumped 3,000 gallons of water per minute from its pond. The water was supplied by one 6-in. and two 10-in. pumps to six 24-in. American jigs and sluice boxes for gold recovery.

A dredge works on the principle of the bucket line. The Sumpter dredge used 72 cast-iron buckets, each holding 9 cubic feet and weighing a ton. The rate-of-dig was 25 buckets per minute. At this rate, an average month's dredging moved 280,000 cubic yards of earth.

Various dredges used various sources of power. The earliest were steam driven, using cord wood for fuel. Some were gasoline powered, then came diesel. But the most dependable fuel was electricity. When a dredging operation was off somewhere in the mountains, such as the Sumpter Dredge, the operators built a power house, then strung miles of wire to the dredge. For this dredge, the power line was 12 mi long. The bucket line was powered with a 250-hp motor on the end of the 23,000-volt power line from the portable substation at the edge of the pond.

To be historically accurate, one should point out that the present dredge, the potentate of the new Sumpter Valley Dredge State Park, is actually the third Yuba dredge in this valley.

Sumpter No. 1 started digging, moving downstream, in the Powder River on January 13, 1913. It finally ground to a stop on July 23, 1924. The bones of its hull can be seen at the present time right where it stopped: in the swamp just a few feet from the "Dredge Depot" of the Sumpter Valley Restoration Railroad. This is a few hundred yards south of the ghost town of McEwan on Highway 7. As of this writing, no interpretative sign tells the visitor what this scrap pile of old timbers represents.

Sumpter No. 2 operated between October 1915 and 1923. It worked upstream from the town of Sumpter on Cracker Creek in the direction of Bourne. After its work was finished, it was carefully dismantled, except for the hull, and its parts were shipped in 18 railroad cars to a buyer near Liberty, Washington. Here the dredge was reassembled on a new hull. This location is just off Highway 97, a short distance north of Ellensburg. The dredge, now renamed "Liberty Dredge," started scooping up muck on February 22, 1926. But alas, the dredge proved too big for the job, so it was moved to another site close by. Liberty Dredge could bite through a 65-ft bank, but it worked only 71 days, until it was confronted by a 200-ft bank of heavy rock, which it could not conquer. That mining venture folded. The equipment from the dredge was sold and the hull left to the elements. Substantial remains of the structure, now collapsed but still sitting in its pond, are easily found.

Sumpter Dredge No. 3 is the attraction of the new Sumpter Valley Dredge State Park, in Sumpter, Oregon. The State Parks Department bought the rare 1,250-ton machine for $195,000 in 1994. Photo taken June 1994.

Dredge No. 3, the dredge that is now the center of the new State Park at Sumpter, had for its machinery the parts from the original No. 1 dredge. After the final shutdown in 1954, much of the machinery was removed. Because of the huge costs involved in setting up a dredge, it takes years of digging to pay off the investment before profits can be taken. Not all dredge operations are profitable. For Sumpter Valley Dredge No. 3, the setting-up cost was $300,000, but it took out $45 million in gold.

When the Oregon State Parks people complete their reclamation project, the dredge will be a monumental triumph for their rejuvenation efforts and will allow visitors to tour this magnificent, giant Rube Goldberg apparatus. Already, the town of Sumpter is visited by thousands of people who just like to walk around the perimeter of the dredge's pond and gawk at the quiet monster.

Dredging continues today. In California, the Yuba Dredge No. 21 operates 24 hours a day, seven days a week in the Yuba Gold Field about 50 miles northeast of Sacramento. This operation of Cal Sierra Development, Inc., has been there for 16 years. The Yuba No. 21 makes Sumpter Dredge seem a miniature, for No. 21 is 453 ft long and 101 ft high. Its present dig is in its own pond 48 ft below the surface of surrounding terrain. The buckets, 20 cubic feet each (Sumpter Dredge buckets are 9 cu. ft.), dig 140 ft below water level, which makes the dig reach 187 ft below the surrounding land, one of the deepest in the world. □

The beautiful alpine Sumpter Valley was transformed into a gigantic gravel pit, as the dredge moved across the land digging out its gold—$45 million worth of it. Photo taken in July of 1993.

The author, Bert Webber, has also written a book on the subject of dredges,* Dredging For Gold—Documentary, *which was published by Webb Research Group Publishers in 1994.
—ed.

New index of geologic mapping in Oregon released

The Oregon Department of Geology and Mineral Industries (DOGAMI) has released a new index of geologic mapping in Oregon that helps a researcher to identify all geologic maps ever produced by DOGAMI, the U.S. Geological Survey, and the Oregon Water Resources Department for any given area in the state.

Index to Geologic Maps of Oregon by U.S. Geological Survey Topographic Quadrangle Name, 1883-1994 is the title of the new index that has been released as Open-File Report O–95–4. It was compiled by Peter L. Stark, Head of the Map and Aerial Photography (MAP) Library at the University of Oregon Library in Eugene.

The index has 67 pages with over 3,450 entries in an alphabetic list of all 15-minute and 7½-minute topographic map quadrangles in Oregon for which geologic mapping has been done. Quadrangles whose names have been changed over the years are listed under each of their names. Each quadrangle name is followed by references to publications by DOGAMI, the U.S. Geological Survey (USGS), or the Oregon Water Resources Department. Entries also include the scale of mapping and comments on the extent of coverage in the quadrangle. Only those geologic maps are listed that are at a scale of at least 1:125,000 (one inch = two miles), most commonly 1:62,500 or 1:24,000.

While it is first and foremost a library tool, the index can serve as a useful, up-to-date bibliographic reference for geologic information. Many publications that include geologic maps are comprehensive studies of particular subjects or areas. The required quadrangle name for a given area of interest can be easily obtained from the U.S. Geological Survey or any place where maps are used or sold.

For ordering instructions, see the last page of this issue. □

Workshop on Ames structure in Oklahoma

A workshop on "Ames Structure and Similar Features" will be held at the University of Oklahoma on March 28–29, 1995. The program will present research and studies dealing with meteorite-impact craters (such as the Ames structure in northwestern Oklahoma), exploration, reservoir characterization, geochemistry, remote sensing, and other subjects related to development of petroleum resources.

The Ames structure in Oklahoma was formed by meteorite impact, volcanic activity, or dissolution/collapse. It is 6–10 mi across, buried beneath 9,000 ft of sediments, and is a prolific source of oil and gas. Similar structures have been found in various parts of the United States as well as worldwide.

The workshop, which will also include a poster session, is sponsored by the Oklahoma Geological Survey and the Bartlesville Project Office of the U.S. Department of Energy. For the two-day workshop, 1.5 Continuing Education Units (CEUs) are available. Further information is available from the Oklahoma Geological Survey, 100 E. Boyd, Room N-131, Norman, OK 73019-0628, phone 405-325-3031. □

THESIS ABSTRACTS

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

Geology and mineralization of the Ochoco gold prospect, Crook County, Oregon, by Dana C. Willis (M.S., Oregon State University, 1992), 97 p.

The Ochoco gold prospect is located in the Ochoco Mountains of central Oregon, 26 mi east of Prineville. Small-scale placer and lode mining in the Howard Mining District of central Oregon began in the early 1800s, with the principal placer workings along Scissors Creek and Ochoco Creek. Lode production from the district was mainly from the Ophir-Mayflower mine (Ochoco mine), with minor production from several other small workings. Placer mining decreased in importance as the placers were worked out in 1883; lode mining continued until the last reported production in 1923.

The Ochoco gold deposit is within the Ochoco Mountains subprovince of the western part of the Blue Mountains province. Generally, the Ochoco Mountains are a broad uplifted region of Miocene-Eocene volcanic rocks that uncomformably overlie Cretaceous and older marine sedimentary and metamorphic rocks. The deposit is roughly halfway between the Blue Mountain anticlinorium to the northwest and the Post anticlinorium to the southeast. These broad, parallel, folded uplifts account for much of the deformation in the region. Several smaller, parallel-fold axes are found between the large anticlinoria and are roughly parallel to the Ochoco Creek fault zone, which bounds the study area on the northwest.

The Clarno Formation, which hosts the deposit, is a terrestrial calc-alkaline assemblage of flows, plugs, dikes, volcanic breccias, mudflows, ash flows, and tuffaceous sedimentary rocks and lahars of widely variable thickness, probably erupted from stratovolcanoes. The Clarno Formation varies in composition from alkali olivine basalt on the basis of isotopic ages and faunal evidence and ranges in age from 54 to 37 Ma. K-Ar age determinations place the age of the host rocks at 50.8 Ma and mineralization at 46.4 Ma.

Volcanic rocks within the project area are chiefly intercalated andesite tuffs, breccias, andesite to basaltic andesite flows, and flow breccias. These rocks, subdivided by mineralogy and texture, are confined to a few map units because of limited exposure and the effects of hydrothermal alteration.

Structures in the study area are predominantly high-angle normal faults that offset Clarno Formation volcanic rocks. There appear to be two, possibly three, different sets of faults based on their strike and cross-cutting relationships. Ochoco Creek follows the main fault along a N. 40°–60° E. strike, with secondary faults in Scissors Creek striking at N. 40° E. and N. 60° E. These en-echelon faults cut and offset small faults that strike N. 60° W. Several late-stage breccia pipes cut across the early andesite flows.

Hydrothermal alteration and mineralization in the project area are probably related to Eocene-age intrusions that acted as a heat source for the hydrothermal system. This hydrothermal system was centered above and around an intrusion of intermediate composition. A broad zone of weak alteration is characteristic of the area, with local zones of moderate to strong alteration in and around structures and breccia pipes. On a broad scale, the areal distribution of alteration displays a crude zonation, with intensity of alteration decreasing away from the center of mineralization. Weak propylitic alteration is pervasive throughout most rocks in the area and intensifies with proximity to faults, fractures, and breccia bodies. The propylitic assemblage is characterized by secondary minerals of calcite + chlorite + pyrite ± sericite. Mineralogy of the intermediate argillic alteration is characterized by sericite + calcite + pyrite ± clay ± chlorite. The intensity of argillic alteration ranges from incipient, in which modest amounts of sericite and calcite replace feldspar, to advanced, where the feldspar and hornblende are completely replaced by sericite ± clay. Advanced argillic alteration is characterized by clay minerals and sulfides replacing the host rocks within narrow structural zones.

Ore mineralogy at the deposit is fairly simple, consisting of ubiquitous pyrite and subordinate amounts of sphalerite, galena, chalcopyrite, tetrahedrite, pyrrhotite, maracasite, stibnite, cinnabar, realgar, argentite, and minor supergene minerals. The bulk of the gold is associated with pyrite, although visible gold is scarce. Mineralization is of two types: pyrite occurring as dissemination and veinlets and calcite veinlets with intergrown pyrite, sphalerite, galena, chalcopyrite, and tetrahedrite(?), with minor rhodochrosite.

Exploration drilling in the area has yielded over 11,000 assays for gold, silver, antimony, lead, zinc, arsenic, and copper. Concentrations of these metals range up to 5 ppm Au, 90 ppm Ag, 0.2 percent Sb, 0.6 percent Pb, 0.6 percent Zn, 0.2 percent As, and 450 ppm Cu. There is a median gold-to-silver ratio of 1:11.

Geologic characteristics of the deposit place it into the volcanic-hosted Au-Ag epithermal deposit category, with some features found in the Cordilleran vein-type deposit. This deposit is unusual in that it has anomalously higher base-metal concentrations and lower precious-metal concentrations than are found in typical Au-Ag epithermal deposits.

Coastal crossing of the elastic strain zero-isobase, Cascadia margin, south-central Oregon coast, by Gregory George Briggs (M.S., Portland State University, 1994), 251 p.

The analysis of marsh cores from the tidal zones of the Siuslaw, Umpqua, and Coos River systems on the south-central Oregon coast provides supporting evidence of coseismic subsidence resulting from megathrust earthquakes and reveals the landward extent of the zero-isobase. The analysis is based on lithostatigraphy, paleotidal indicators, microfossil paleotidal indicators, and radiocarbon age. Coseismic activity is further supported by the presence of anomalous thin sand layers present in certain cores. The analysis of diatom assemblages provides evidence of relative sea-level displacement on the order of 1 to 2 m. The historic quiescence of local synclinal structures in the Coos Bay area together with the evidence of prehistoric episodic burial of wetland sequences suggests that the activity of these structures is linked to megathrust releases. The distribution of cores containing non-episodically buried marshes and cores that show episodically buried wetlands within this area suggests that the landward extent of the zero-isobase is between 100 km and 120 km from the trench. The zero-isobase has a minimum width of 10 to 15 km. Radiocarbon dating of selected buried peat sequences yields an estimated recurrence interval on the order of 400 years. The apparent overlapping of the landward margin of both the upperplate deformation zone (fold and/or thrust fault belt) and the landward extent of the zero-isobase is interpreted to represent the landward limit of the locked zone width of 105 km. The identification of the zero-isobase on the south-central Oregon coast is crucial to the prediction of regional coseismic subsidence and tsunami hazards, the testing of megathrust dislocation models, and the estimation of megathrust rupture areas and corresponding earthquake magnitudes in the Cascadia Margin. □

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