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IN THIS ISSUE:

EPISODICALLY BURIED FORESTS IN THE OREGON SURF ZONE

NATIONAL OUTSTANDING RECLAMATIONIST OF THE YEAR: E. FRANK SCHNITZER

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Cover photo

Rooted stump on the wave-cut platform near Moore Creek south of Newport. The stump was exposed in February 1996. Based on the size of the roots, the trunk is estimated to have been at least 2 m in diameter. Related article on episodically buried forests along the Oregon coast begins on next page.

DOGAMI revises map production

The Oregon Department of Geology and Mineral Industries (DOGAMI) has added to its publications two new map series that represent different types of mapping detail and mapping subjects. The first product of a new series, map IMS-1, is expected to be released before the end of this year. The following is an excerpt from the revised section on geologic maps in the Department's policy manual:

"DOGAMI produces three separate map series, all are subject to multiple external peer review.

"1. **GMS** (Geologic Map Series) maps are complete and detailed and prepared (though not necessarily published) at 1:24,000 or smaller scale. These maps include, where appropriate, chemical data, age data, paleontological data, petrography, geophysics, water-well data, and other types of specific geologic information.

"2. **RMS** (Reconnaissance Map Series) maps are lower resolution maps aimed at rural areas with scant existing information, which do not justify GMS-level effort. These will normally be compiled at 1:24,000 but generally published at 1:100,000. Individual 1:24,000 sheets may be released as separate RMS maps. RMS maps will require compilation of existing mapping, resolution of nomenclature, correlation of units, driving all major roads, and complete air-photo and imagery interpretation. The goal of these maps is to unify and clean up existing mapping, and to ensure that most major units or structures have been identified, if not mapped accurately. It is likely that future more detailed mapping in these areas would identify significant new features. Each sheet should be anchored by GMS-level mapping of at least one 1:24,000 quadrangle.

"3. **IMS** (Interpretive Map Series) maps are geology based but depict an interpretation of some characteristic based on geology. Examples would be maps showing hazard zones, aggregate resources, engineering properties, groundwater-related data, geophysical interpretations, etc. These maps would be published at a variety of scales, depending on the issue covered." □

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Klaus K. Neuendorf, Editor

Episodically buried forests in the Oregon surf zone

by Roger Hart, College of Oceanic and Atmospheric Sciences, Oregon State University, Hatfield Marine Science Center, Newport, Oregon 97365; and Curt Peterson, Department of Geology, Portland State University, Portland, Oregon 97207

ABSTRACT

Severe winter storms, especially in ENSO[1] years, expose rooted tree stumps in the surf zone of the central Oregon coast. Root mats up to 6 m in diameter are anchored in the Tertiary rocks of the late Holocene wave-cut platform. We studied more than 275 stumps at 14 localities between Neskowin and Coos Bay. Forest soil preserved beneath some roots can be traced landward, where it overlies creek mouth marsh and paleosand dune deposits. The stump fields and the forest soil are remnants of a continuous forest or series of forests that extended farther seaward than present-day temperate coniferous rain forest. Litter in the soil indicates that the forest soil was rapidly buried. Ages of the rooted stumps range from 1,970 ± 50 to 4,340 ± 70 radiocarbon years before the present (RCYBP).

Eustatic change of sea level and migration of sand barriers are considered as explanations for preservation of rooted stumps at some sites. However, large-diameter stumps rooted on continuously active late Holocene wave-cut platforms depleted of littoral sand are indicators of tectonic movements on the central Oregon coast. A necessary history requires six stages: (1) wave cutting of platform at sea level, (2) tectonic uplift of the platform, (3) growth of the forest on the wave-cut platform, (4) rapid burial and preservation of the forest, (5) inundation of the forest at sea level, and (6) renewed erosion of the beach platform. These results corroborate salt-marsh evidence of late Holocene vertical tectonic displacements associated with local or regional earthquake sources along the Oregon coast. Further radiocarbon dating of annular rings in the rooted stumps and preserved litter in the soil can potentially constrain the nature, age, and extent of the tectonic displacements.

INTRODUCTION

For several decades, scientists have reported tree stumps rooted on the wave-cut platforms of the surf zone along Oregon beaches (Kelley and others, 1978; Peterson and others, 1993; oral communications from R. Bayer, Yaquina Birders and Naturalists, 1985; E. Zoebel, Department of Botany, Oregon State University, 1995; and R. Loeffel, Fisheries Manager, retired, 1996). However, no systematic study of these rooted stumps has been published. The stumps stand upright, with broad root mats spread parallel to the wave-cut platform (cover photo). They have been observed in place for over ten years, even during periods when the surrounding sand has been stripped from the beach. Although some stumps may be rooted in submerged late Pleistocene stream channels, most are rooted in the Tertiary bedrock of the late Holocene wave-cut platforms. Similar roots associated with currently living trees are found only inland from the surf zone. The live trees that left the stumps on the beach must have grown on the wave-cut platform after regression of the surf zone. Following at least several hundred years of growth, transgression of the surf zone must have invaded the tree growing zone. These observations led to early concepts of late Holocene seismic activity along the central Oregon coast (Darienzo and Peterson, 1990).

We report on a study of 1.9- to 4.4-ka (kilo-annum = 10^3 years) trees rooted on the wave-cut platforms of the central Oregon coast, lat 43.23°–45.00°N. (Figure 1). We document the association of forest soils, debris flows, and liquefaction features with the buried stumps. In the discussion, we evaluate three mechanisms for regression and transgression of the surf zone: (1) growth and removal of sand barriers, (2) eustatic change of sea level, and (3) vertical tectonic displacement of the Cascadia margin. We use observed stratigraphic relations to rule out mechanisms 1 and 2 at most localities.

BACKGROUND

The beaches of the central Oregon coast occupy late Holocene wave-cut platforms, at least several hundred meters in width, that are carved in late Pleistocene marine terrace deposits or in Tertiary sedimentary rocks. South of Newport, the surf zone may have reoccupied late Pleistocene platforms (Ticknor, 1993). North of Newport the youngest apparent Pleistocene platform is elevated as much as 30 m above present sea level.

In general, elevated wave-cut platforms underlie a series of inland marine terraces composed mainly of Pleistocene beach and dune sand (Kelsey and others, 1994; Ticknor, 1993).

Ticknor (1993) used the uplifted platforms to calculate average vertical displacement rates for the past 105 ka and found 0.85 ± 0.06 mm/year north of Newport and -0.01 ± 0.03/year for the area around Yachats.

[1] El Niño Southern Oscillation. El Niño refers to the equatorial Pacific warm water anomaly. The Southern Oscillation traditionally refers to associated variations in atmospheric circulation in the south Pacific. Recently, teleconnection links to enhancement of the Aleutian low-pressure system off the Oregon coast have been documented and are thought to cause an increase in storminess and associated coastal erosion.

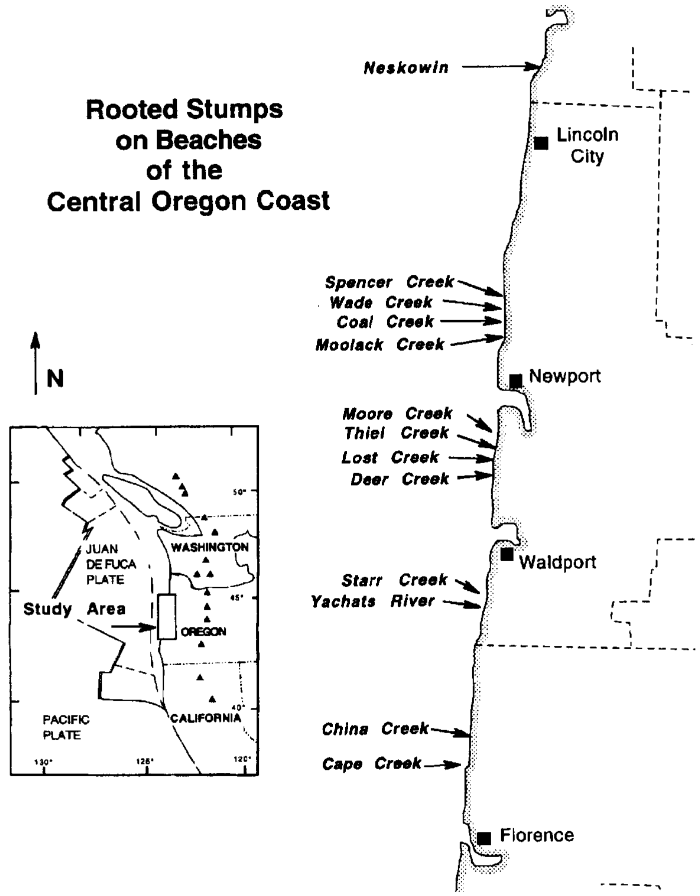

Figure 1. Location of the study area where rooted stumps have been mapped. The stump field at Sunset Bay discussed in the text and referred to in Table 1 is south of the enlarged area.

Mitchell and others (1994) calculated present-day vertical displacement rates from repeated leveling surveys and tide gauge records. Their results indicate that, at the present time, the area around Newport is stationary or subsiding, whereas the area around Yachats is being uplifted.

The wave-cut platforms in the vicinity of Newport terminate landward in wave-cut cliffs; whereas, the wave-cut platforms north and south of Yachats most frequently terminate landward in Holocene foredunes.

RESULTS

More than 288 rooted stumps were mapped at 14 localities between Coos Bay and Neskowin, a distance of 206 km (Figure 1). Additional rooted stumps and soil profiles were studied and sampled at seven localities in creek mouths and backshore deposits. We collected 26 wood samples and 59 soil samples from beaches, creek mouths, and soil run-ups and examined them under the microscope. Over 60 km of beaches, marine cliffs, and creek mouths were photographed and mapped on either U.S. Geological Survey 1:24,000-scale (7½-minute series) topographic maps or on 1:4,800-scale aerial orthophoto maps used by Priest and others (1994). Details of the mapping and sampling are given in Table 1.

Rooted stumps

Normally, 1–5 m of beach sand covers the stumps in the surf zone (Figure 2), but they are exposed during periods of extreme beach sand erosion, most commonly during the winters of

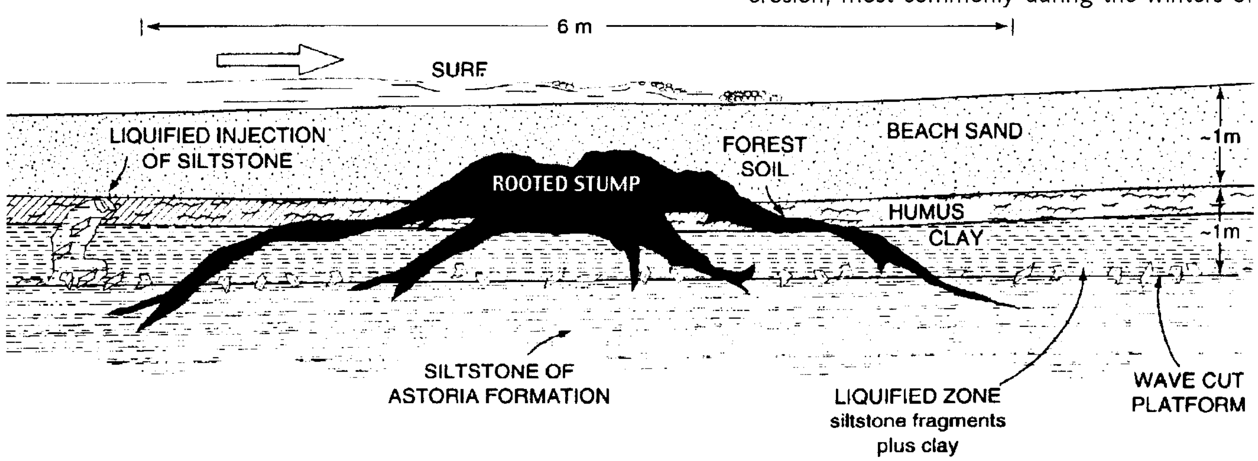

Figure 2. Diagrammatic figure of the principal features of the buried stumps beneath beach sand. The roots extend into the Tertiary siltstone on which the platform was cut. Some of the stumps have erosional remnants of forest soil with fresh litter, humus, and gray clay directly on the wave-cut platform. The inferred liquefied injection of siltstone fragments into the soil was probably coseismic but not necessarily synchronous with burial of the rooted stump.

strong ENSO events such as 1973/74, 1982/83, and 1994/95 (Peterson and others, 1990; Komar, 1986). Rooted stumps in the surf zone at Deer Creek, Moolack Creek, Coal Creek, Wade Creek, and Spencer Creek, first noted during the 1982/83 ENSO, have since been episodically exposed (R. Bayer, oral communication, 1995). New exposures occurred at nine localities during the 1994/95 ENSO.

The rooted stumps in the surf zone were exposed for variable lengths of time. Those at Wade Creek and Yachats River were exposed for less than a month. The stumps at Thiel Creek were exposed for more than ten months. Two photographs of the Thiel Creek stump field are shown in Figure 3; the first one was taken January 24, 1995, just after initial exposure, the second one on May 17, 1995. Shortly after exposure in 1995, the logs and stumps at Thiel Creek were colonized by algae (*Enteromorpha)* and a species of the bay barnacle (*Balanus)* (Figure 3). There was no evidence of prior colonization, which suggests that the rooted stumps were not previously exposed during an epifaunal growing season. The Thiel Creek stump field was completely covered by sand by October 1995 but reappeared briefly in February and December of 1996 and January of 1997. Relics of the previous algae and barnacle colonization were apparent upon re-emergence. Stumps exposed during the 1982/83 ENSO at Neskowin had substantially decayed by 1995 (Figure 4).

The rooted stumps are in clusters of from 3 to 200. The roots spread parallel to the beach platform and extend radially outward up to 6 m (Figure 4). In places, bark with the general appearance of present-day western hemlock (*Picea sitchensis)* is intact. Complete annular-ring records are intact in some stumps and roots (Figure 4). The trunks are generally not preserved, but trunk diameters estimated by reconstruction of remnants range up to 2 m in diameter (Figure 4).

The absence of trunks may be either because they were broken off or because they decomposed faster than the roots. Wind, storms, tsunamis, or debris flows could have broken off the trunks. However, most of the stumps exposed in the surf zone do not show evidence of breakage, i.e., no splintered ends have been observed. Yet, rooted stumps exposed landward of the backshore in creek mouths and dune fields do have splintered ends (Figure 4). The absence of splintered ends on the surf zone stumps may be due to abrasion by waves and moving sand.

Alternatively, the trunks may have decomposed, and the roots were preserved by partial sterilization and/or mineralization in wet, salty, anaerobic sand. Indeed, the outer portions of the surf zone roots in contact with wet sand are better preserved than the cores (Figure 4).

The following radiocarbon ages were derived from rooted stumps: 1,970 ± 50 RCYBP at Neskowin, 3,920 ± 60 RCYBP at Deer Creek, and 4,340 ± 70 RCYBP at

Figure 3. Comparison photographs of the stump field at Thiel Creek. The stump in the foreground of the top photograph, taken January 24, 1995 is rooted and the same as the one in the one in the middle of the bottom photograph, taken May 17, 1995. The freshly exposed stump in the top panel is devoid of barnacles and algae. The same stump in the bottom panel is more fully exposed and has been colonized by barnacles of the genus *Balanus* and marine algae of genus *Enteromorpha*. The other logs in the photograph, tilted by folding, are unrooted, embedded in soil and clay, and were similarily colonized by barnacles and algae.

Wade Creek. The uncertainties in the relationship between tree death and forest subsidence and/or inundation prohibits correlation of these dates with other tectonic events.

Some trees may have died but may have been preserved before a given event. Snags, dated by forest fire scars, stand up to 150 years after death of the tree. Roots persist even longer, especially if buried by a debris flow or in a peat bog. On the other hand, trees that are only partially buried during inundation on the backshore beach, such as Deer Creek DC-3, may have continued to grow after trees that were submerged in the surf

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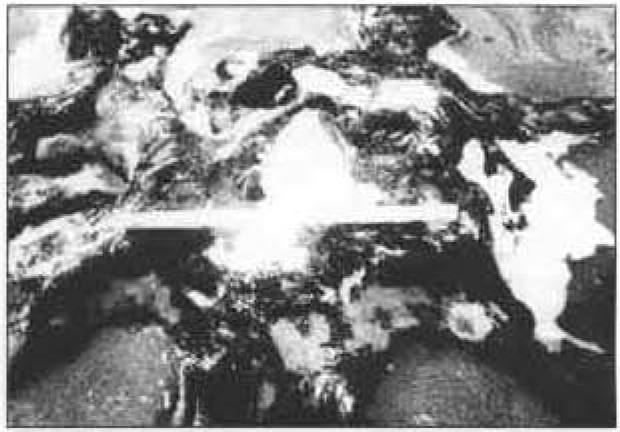
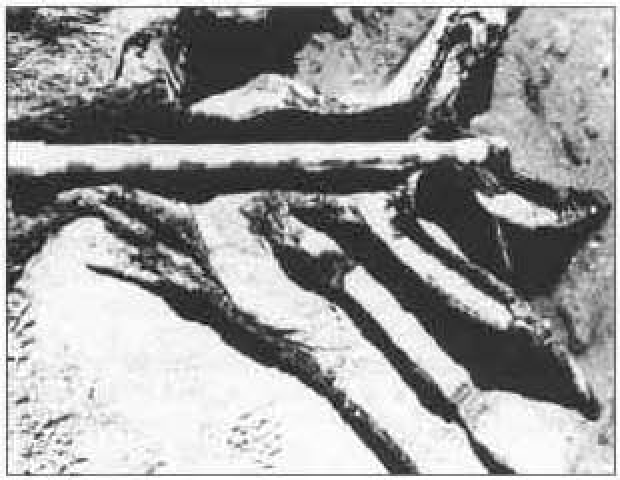
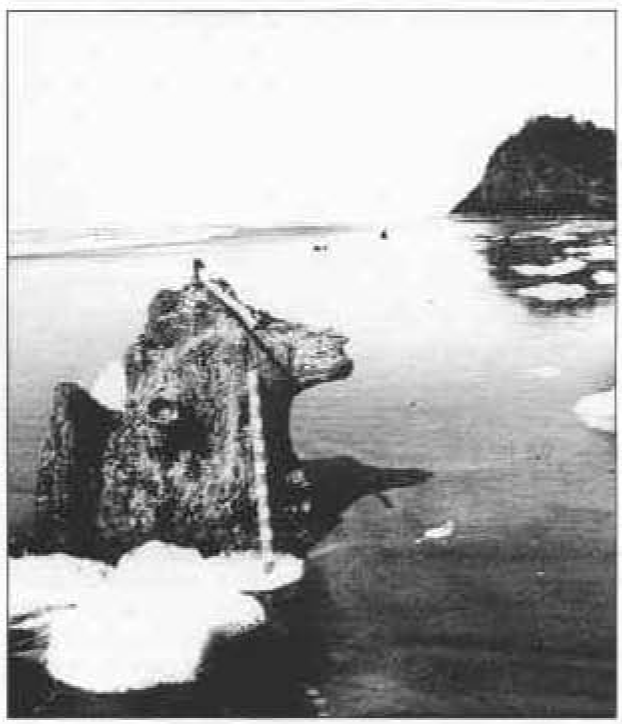
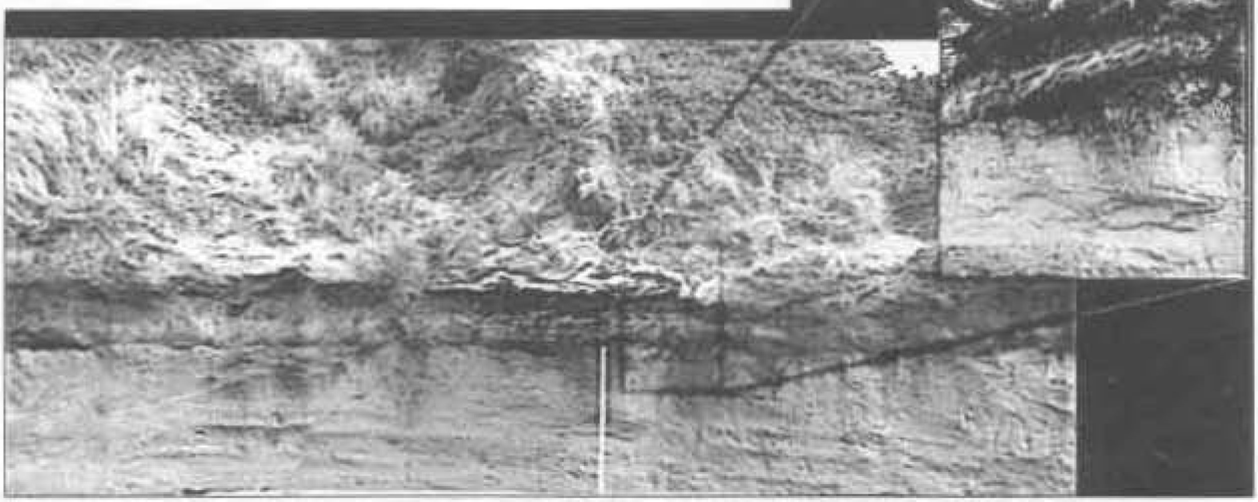






← Figure 4. Photographs of rooted stumps: Upper left is a photograph taken on the wave-cut platform near Wade Creek and shows a root 6 m in diameter. Radiocarbon age derived on a wood sample from this stump is 4,340 ± 70 RCYBP. Upper right is a photograph of a surf zone rooted stump at Deer Creek. The root core is intact and greater than 1 m in diameter. Middle left is a photograph of a rooted stump at China Creek, located on the backshore beach. Two layers of forest soil underlying late Holocene foredunes are apparent in the small wave-cut cliff behind the stump. This soil is a continuation of the surf zone forest soil shown in Figure 5. Forest soil with litter underlies the beach sand and cobbles in the foreground. The stump is 5 m in diameter and displays a splintered top. Middle right is a photograph of a rooted stump at Sunset Bay. The cores of the root have decayed, which suggests that the outer layers are more resistant to decomposition. Lower left is stump embedded in the marine cliff at Deer Creek. Dimeter of root branch is >1 m, suggesting trunk was at least 2 m in diameter. Lower right is a stump on the wave-cut platform at Neskowin. In the background is Proposal Rock.



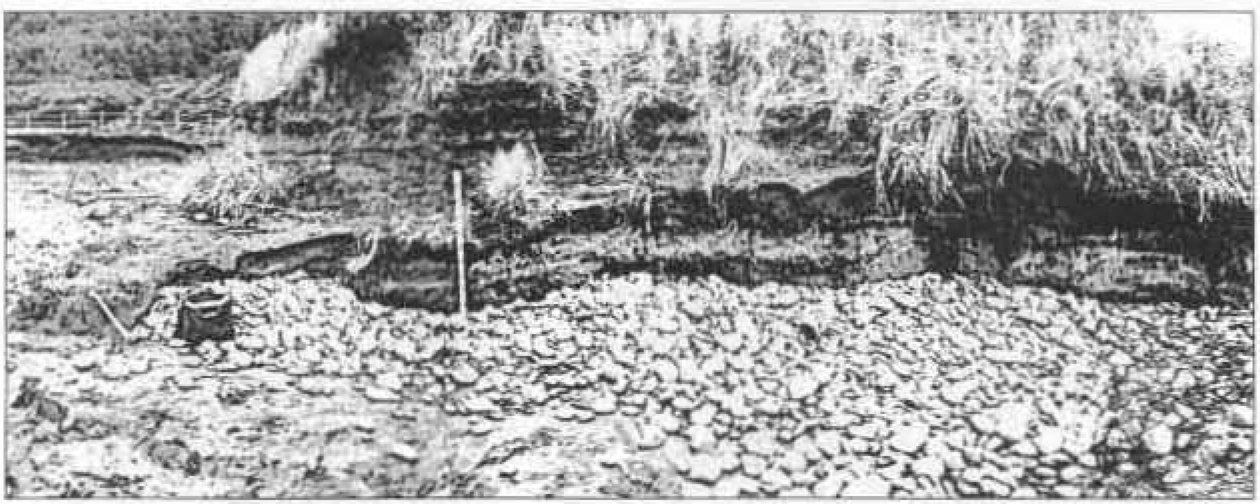


Figure 5. Podzol horizons: Top photograph shows forest soil with podzol profile exposed in the marine cliffs near Blowout Creek. Insert shows a rooted stump in place. Elevation of the soil above the beach is about 2.6 m. The soil can be traced continuously southward to the ascending soil horizon shown in Figure 7. Bottom panel is a photograph taken at China Creek. Forest soil is exposed on the beach in the left foreground. The soil can be traced continuously from the beach, up the ramp behind the ax (left middle ground) to the small wave-cut cliff at the top of the beach. Five rooted stumps are present on the beach and in the cliffs just to the south (right) of this location (see Figure 4). Cones of the western hemlock, *Tsuga heteropylla*, and Sitka spruce, *Picea sitchensis*, were sampled from the beach in the foreground (see Figure 8).

(Continued from page 133)
zone died. The radiocarbon ages do constrain the forest growth to late Holocene times and suggest that undecomposed litter fragments and individual tree rings may contain sufficient radiocarbon for more detailed studies.

Forest soil

A 5- to 30-cm-thick layer of organic rich soil is preserved under and around the rooted stumps on the beaches at Neskowin, Thiel Creek, China Creek, and Sunset Bay. The soil can be traced landward into creek mouths, beneath Holocene foredunes, and upslope to dune deposits that cap the top of marine cliffs (Figures 5, 6, 7). Forest soil horizons are identified by litter and well-developed Podzol profiles. The litter includes cones, needles, moss fragments, and shredded bark (Figure 8). The Podzol profiles, with a pronounced leached zone typical of temperate rain forests, are best developed on ascending soil horizons that stratigraphically tie surf zone forests to deposits on top of the marine cliffs (Figures 5, 7).

The soil layer on the beach at China Creek is less than 0.5 m thick and underlies the Holocene foredunes as shown in Figure 5. Since the rooted stumps are anchored in their growing position, the soil must be in situ. At China Creek, the soil is compact, plastic, and rich in organic matter and gray clay. It is typified by three zones: (1) an upper litter-rich zone; (2) a humus-rich layer; and (3) a clay layer with matrix-supported clasts of underlying rock that have been injected into the clay (Figure 2).

The litter-rich zone at China Creek includes cones, fragments of moss, needles, diatoms, twigs, branches, and woody debris (Figure 8). The cones are similar to that of Sitka spruce (*Picea sitchensis)* and western hemlock (*Tsuga heterophylla)*. The moss stems and leaves belong to a bryophyte similar to present-day *Scouleria aquatica*. The conifer needles are similar to those of *Picea sitchensis* and show intact stoma structures. The dark-brown humus underlying the litter is dense and compact with matrix-supported clasts of the underlying Tertiary siltstone.

The soil, where exposed in the lower low-water zone, was colonized and degraded by burrowing clams similar to the rough piddock (*Zirfaea pilsbryi)*.

The paleo-soil profiles at the creek mouth, exposed at eight localities (Table 1), are stratified, with a layer of

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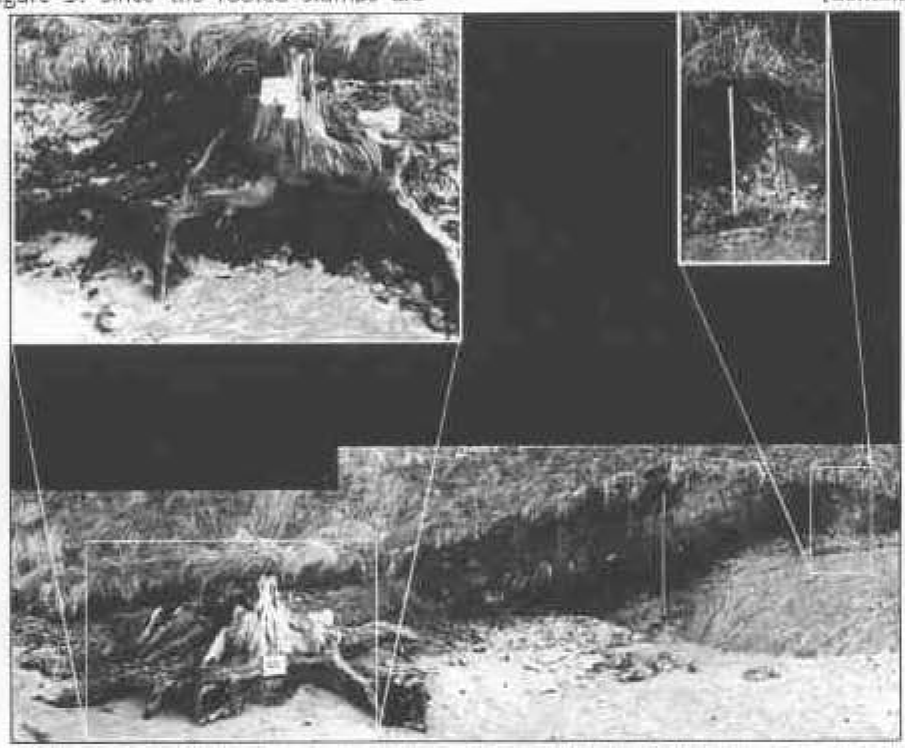

Figure 6. Orthophoto panorama taken at Deer Creek of rooted stump DC–3. Forest soil ascends onto the uplifted wave-cut platform. Inserts depict closeup of the stump and a coseismic liquefaction feature. Radiocarbon age of the stump is 3,920 ± 60 RCYBP. Forest soil is exposed under stump, and runup is continuously exposed to top of marine cliffs. It is inferred that the soil is the same age as the stump. It is also inferred that the liquefaction feature is coseismic because of the lack of overburden capable of inducing load structure, but it could be younger than the rooted stump and soil.

Table 1. *Rooted stumps and forest soil localities*

Locality	Access	Stump field	Soil	Samples
1 Neskowin	Cross Neskowin Creek south to Prospect Rock. Upright stumps in the surf zone south to basalt cliffs.	Over 200 upright stumps exposed in winter of 1983. In winter of 1995, about 20 stumps exposed but degraded by shipworms and boring clams (Figure 4).	Some soil remnants in surf zone, but mostly eroded away.	Carbon-14 age on one sample by C. Peterson 1983: 1,970 ± 50 RCYBP, Beta Analytical No. 26128. Sample NS-1 collected 3/95 by RH. An age of 1,730 ± 160 RCYBP reported by Kelley and others, 1978.
2 Logan Creek	Forest soil and debris flow underlie parking lot at Road's End Beach State Wayside. Debris flow also exposed in bank at base of access path.	None observed.	Soil runs up from creek mouth to top of marine cliff under parking lot (Figure 9).	Soil profile measured and sampled on marine cliff SW of parking lot. Soil samples, LC-1 debris flow; LC-2, forest litter (L-zone); LC-3, forest humus (H-zone); LC-4, leached dune sand (E-zone), sesquioxide-enriched dune sand (B-zone); LC-5, clay layer of uncertain origin.
3 Lincoln Beach	Access beach for 900–1,800 m N. from Fishing Rock. Rooted stumps and forest soil buried in driftwood line.	7 stumps reported 5/97 by Don Christensen (DOGAMI Govering Board member from Depoe Bay).	Soil ascending from beach to top of low marine cliffs. Observed 5/97. Fire-scorched horizons noted.	1 stump sample with intact core, LB-1, sampled by Don Christensen 5/97.
4 Spencer Creek	Access from Beverly Beach State Park; 2 stumps 100 m S. of creek on beach backshore.	2 rooted stumps exposed 3/95.	Debris flow on bank of creek under Hwy 101 bridge and on E. side of highway.	No samples.
5 Wade Creek	Descend gravel road to beach from Hwy 101 turnout, 1 mi S. of Beverly Beach. Largest stump is visible from the highway.	3 rooted stumps exposed 3/10/95 to 3/25/95 S. of creek runout. Largest stump re-exposed for one week in 2/96 (Figure 4). 7 additional stumps first exposed 4/97.	Creek mouth forest soil and blue clay exposed in bank at top of beach next to marine cliffs. Debris flows exposed W. of highway on top of marine cliffs.	Wood sample WC-1, carbon-14 dated at 4,340 ± 70 RCYBP, Beta Analytical No-89166. Bark sample WC-2 similar to *Picea sitchensis*.
6 Coal Creek	Descend marine cliff from abandoned Hwy 101 turnout just S. of Carmel Knoll. Stump field and soil profile are located 150 m N. of creek mouth.	5 rooted stumps exposed in roughly E.-W. line from bank at backshore of beach to lower low-water zone. First reported intermittent exposures 1985–1992 by R. Bayer. Re-exposed 3/95–6/95.	Debris flow deposit covers stump in bank at top of the beach. Forest soil covered with debris flow at top of marine cliff extends 375 m to N.	Wood sample CCS-3 taken from rooted stump at high-water line. Soil section measured in the marine cliff.
7 Moolack Creek	Descend on path from parking lot at Moolack Beach State Park. Soil and debris flow exposed 1 m below present day soil. Rooted stump 100 m directly W. on beach.	1 rooted stump exposed 3/96 in high-water zone.	Forest soil covered by debris flow exposed in marine cliff.	Soil profile measured. Wood sample MC-1 collected 3/96.
8 Schooner Creek	W. down gravel road 170 m N. of Schooner's Landing. Debris flow, forest soil, and creek mouth marsh underlie parking area at end of road.	None observed on beach. 5–6 present in creek mouth soil profile beneath parking area.	Layered forest soil covered by debris flow covers blue clay with marsh grass. Complex stratigraphy because of liquefaction and debris infall.	4 soil profiles measured. Sample SC-1 of debris flow. Samples SC-1, SC-2, and SC-3 of cones similar to *Picea sitchensis* from litter in forest soil.
9 Nye Creek	Marine cliffs N. of Nye Beach turnaround exhibit forest soil and creek marsh horizons with cross-cutting relations.	None observed.	Forest soil on top of marine cliffs with dense mats of litter and bark is overlain by debris flow.	Forest soil sample NB-1. Mat of compact forest litter.
10 Grant Creek	Enter beach access through Pacific Shores residential area or walk 2 km S. from South Beach State Park. Soil profile and rooted stump exposed in bank in creek mouth.	One rooted stump in creek mouth marsh deposit.	Debris flow overlying layered forest soil and creek mouth marsh deposit.	Sample GC-1, debris flow; GC-2, forest soil; GC-3, scorched forest soil; and GC-4, marsh clay. Wood sample GC-1.

Table 1. *Rooted stumps and forest soil localities, continued*

Locality	Access	Stump field	Soil	Samples
11 **Moore Creek**	Walk 1.2 km N. on Holiday Beach from Thiel Creek to mouth of Moore Creek.	1 rooted stump on beach 200 m directly W. of creek mouth exposed 3/96 (cover photo). 1 rooted stump in creek mouth marsh deposit in bank at top of beach.	Creek mouth marsh and overlying forest soil.	Wood sample MC-1 taken from stump on beach.
12 **Thiel Creek**	Turnout on Hwy 101, 300 m S. of Thiel Creek motel. Follow path to beach.	2 extensive stump fields. The one S. of creek mouth arches 151 m from high-water zone (139 m W. of marine cliffs) to lower low-water zone. Photograph by P. Komar taken 1/74 shows soil about 6 in. higher than 3/96, with over 100 forest logs and small woody debris embedded in the soil with a preferred E.-W. orientation. 2 rooted stumps exposed 1/94–12/96 (Figure 3). Stump field N. of creek with 3 rooted stumps and about 50 unoriented logs. From 1/24/95 to 10/20/95, possible rooted stump at top of marine cliffs 520 m S. of Thiel Creek.	Extensive forest soil under rooted stumps and around logs in surf zone (Figures 8 and 10). Soil in creek mouth runs up onto marine cliffs and extends 3 km south. Possible debris flow in creek mouth.	Wood samples STC-1 and STC-2 from S. stump field. Wood samples NTC-1 to -3 from N. stump field, collected 3/24/95. Soil samples TCA-0 to -9 from S. stump field, TCS-1 to -11 from soil horizon in lower low-water zone, TCM-1 to -5 from soil horizon in marine cliff. Cone samples TCC-1 to -4 from S. stump field, collected 8/5/95.
13 **Lost Creek**	Descend path from Lost Creek State Park. Stump field exposed 500 m due W. on beach.	Woody debris, oriented and injected logs observed in low low-water 5/95; no confirmed rooted stumps. Possible washout of rooted stump observed by R. Loeffel in 1982.	Creek mouth marsh and forest soil exposed in elevated creek cut 225 m N. of State Park. Forest soil ascends to top of marine cliffs and continues 200 m N. and S. Woody debris and possible stump present at top of elevated wave-cut terrace.	No samples.
14 **Deer Creek**	Turnout 2.2 km S. of Ona Beach State Park on W. side of Hwy 101. Rooted stumps on beach 100 m W. of beach access. Rooted stumps, forest soil, and coseismic liquefaction feature in bank at top of beach 300 m S. to creek mouth (Figure 6).	Good access and continuous exposure. 2 rooted stumps exposed on beach intermittently since 1982. 2 rooted stumps in bank at top of beach (Figure 6), 1 stump in marine cliff just S. of creek cut.	Layered forest soil in bank at top of beach. 2 layers separated by beach sand. Top layer is fire scorched and contains charcoal. Soil ascends to top of marine cliff, unconformably overlies Pleistocene dunes, and continues for 1.2 km S. to Seal Rock State Park, where it crops out around warning signs at beach access.	Wood samples DCS-1 to -5. Sample DC-3 from backshore beach dated at 3,920 ± 60 RCYBP. Soil samples DC-1 to -6. 4 soil sections measured.
15 **Starr Creek**	Stump field exposed in surf zone 50 m N. and S. of Starr Creek.	10–20 roots exposed 1983–1985. Stumps mostly eroded away.	Not observed.	No samples.
16 **Yachats River**	Access from S. side mouth of Yachats River, Yachats Ocean Road State Wayside picnic area. Stump field 120 m N. of stairway to beach.	5 rooted stumps exposed for 3 weeks, 3/95.	None observed.	Wood samples from rooted stumps, YR-1 and YR-3, collected 3/3/95.
17 **Cook's Chasm**	Access on paved path from turnout N. of Cook's Chasm. Rooted stumps, forest soil, and debris flows in cliff face at top of basalt platform.	1 rooted stump at base of cliff.	Three layers of forest soil capped by debris flows.	2 sections measured.
18 **Cummin's Creek**	Forest soil and creek mouth marsh soil in cliffs below parking lot at picnic area at Neptune State Park and extend S. 540 m.	1 rooted stump at top of beach. 1 rooted stump exposed at top of cliff 500 m S. of picnic area.	Forest soil runs up marine cliffs and continues 500 m S. Paleosoil separated from present soil by shell midden, 370 m S. of picnic area.	4 sections measured.

Table 1. *Rooted stumps and forest soil localities, continued*

Locality	Access	Stump field	Soil	Samples
19 **Ten Mile Creek**	Rooted stump, forest soil, and marsh soil at top of beach 75 m S. of beach access from Stonefield Beach State Wayside.	1 rooted stump at the top of the beach.	Creek mouth marsh soil and forest soil at top of beach. Forest soil runs up marine cliffs S. Separated from modern soil by dune sands and shell midden 390 m S. of beach access.	3 sections measured. Wood sample TMC-1.
20 **China Creek**	Access beach from Muriel O. Ponsler Memorial Wayside. 3 rooted stumps on beach 50 m N. of access. Extensive stump field and forest soil horizon on beach S. across China Creek continues 1.2 km S.	3 rooted stumps in beach high-water zone exposed 6/96, 50 m N. of wayside. First noted 1982/83 by E. Zoebel. 5 rooted stumps exposed in higher high-water zone of beach S. of China Creek. 1 stump continuously exposed in bank at top of beach 500 m S. of Creek (Figure 4).	Forest soil on beach with litter S. of China Creek runs up to bank at top of beach and underlies dune field continuously 0.9 km to S. (Figures 5 and 8). Exposed 3/25/95–8/4/95. Extensive fire-scorched layers.	Wood samples from rooted stumps CCs-1, to -5. Cones of *Tsuga heteorophylla* from beach S. of China Creek. Soil samples CC-1, CC-2, and CC-5. 3 sections measured.
21 **Blowout Creek**	Forest soil in bed of Blowout Creek 200 m S. of picnic area beach access at Carl G. Washburne Memorial State Park.	1 rooted stump in marine cliff 12 m S. of Blowout Creek.	Forest soil runs up from Blowout Creek and continues 2.1 km to Heceta Head. Runs up 12 m over large dune form (Figure 7). Litter exposed south of dune form.	Litter sample BC-1. Wood sample BC-1 from stump rooted in soil runup.
22 **Cape Creek**	1 rooted stump on top of beach near picnic area of Devil's Elbow State Park.	1 rooted stump.	None observed.	Wood sample CaC-1.
23 **Sunset Bay**	18 rooted stumps and buried soil horizons on beach and in bed of Big Creek at Sunset Bay State Park.	18 stumps from Big Creek to fault line on N. end of beach. Intermittently exposed since 1983 ENSO.	Laminated soil of uncertain origin underlies beach sand.	Wood samples SSB-1 to -6; soil samples SSB-1 to -17.

(Continued from page 136)

clay underlying a horizon of forest soil. The clay layer, 1–3 m thick, is characterized by rooted stumps, layers of peat, marsh grass fragments, and clasts of siltstone. The forest soil, 0.5–2 m thick, is characterized by humus, litter, and rooted stumps. At some sites, two or more forest soil layers are divided by layers of beach sand and/or cobbles. The bottom forest layer is thickest and contains cones, bark, and needles. The top forest layer is sandy and contains a zone of fire-scorched material with red iron oxide minerals and possible charcoal.

Soil horizons stratigraphically equivalent to the surf zone soil ascend creek mouth valley walls and cross-cut Pleistocene sand-dune deposits of the marine terraces at seven localities (Figures 5, 6, 7; Table 1). The ascending forest horizons are characterized by Podzol profiles similar to the present day profile formed on top of Holocene dune deposits (Corliss, 1973). The top layer of undecomposed forest litter, shredded bark, cones, and twigs in a matrix of sandy loam varies in thickness from 2 in. to 20 in. This layer grades down into the humus layer which is 10–54 in. thick. The humus is friable with a few firm aggregates, slightly sticky, and nonplastic. Woody debris is locally abundant, and in places 10-cm-thick mats of bark and shredded bark are present. The gray leached zone, which varies from 0.1 to 1 m in thickness, is underlain by an orange-red B horizon 0.5–2 m thick and with well-developed laminae of sesquioxides. The forest soil horizons terminate abruptly upward and are capped by Holocene debris flows, backshore beach sands, or dune sands that separate them from the present-day soil horizon.

Debris flows up to 5 m thick cover creek mouth and ascending forest horizons at nine sites (Table 1). The debris flows contain fragments of the underlying forest soil, angular dune-paleosol fragments, semiangular siltstone fragments, and woody debris mixed in with gravel and mud. The high abundance of angular and unconsolidated fragments suggests that the flows did not travel long distances. At Coal Creek, a debris flow covers a rooted stump at the backshore edge of the beach, which suggests a possible coincidence between platform subsidence and the debris flow. The debris flows probably extended onto the wave-cut platform.

DISCUSSION

The location and abundance of the tree stumps and associated soil indicate that they are erosion remnants of extensive forests that grew on Holocene wave-cut platforms. Several questions are raised by the data: (1) what caused regression of the surf zone off the late-Holocene wave-cut platform? (2) what caused inundation and burial of the established forests? and (3) what was the extent and timing of the burial events? In this section, we discuss each of these questions in turn.

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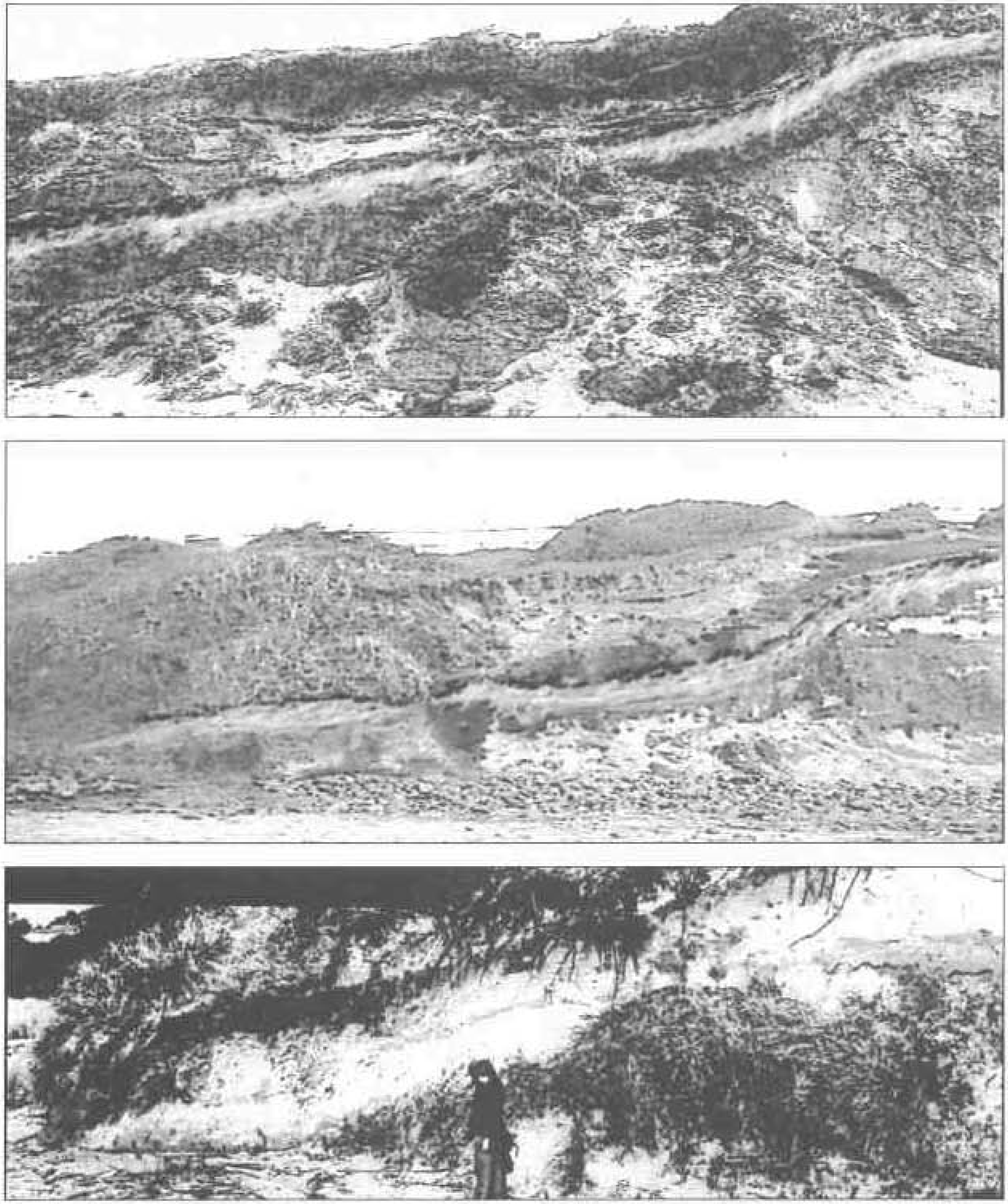

Figure 7. Ascending soil horizons cross-cut older beach and dune sands. Top panel shows well-developed podzol horizon in the ascending forest soil horizon at Blowout Creek. Soil in this photo attains elevation of 8 m and is overlain by Holocene dune deposits. Middle panel shows ascending forest soil horizon below the Road's End parking lot at Logan Creek. Bottom panel shows the ascending forest soil horizon near Wakonda Beach north of Starr Creek.

Figure 8. Buried forest litter. Top panel shows cones and shredded bark from the soil horizon in the marine cliffs at Blowout Creek. Bottom panel shows cones and moss fragments from the litter zone in the soil in the surf zone near China Creek.

(Continued from page 139)

Regression of the surf zone

The surf zone must have receded offshore after the cutting of the platform and before the forest grew on it. Three possible mechanisms of surf zone regression are (1) eustatic drop of sea level, (2) transient sand barrier formation, or (3) tectonic uplift of the coast.

If the wave-cut platforms on which the stumps are now rooted were cut during the previous interglacial high stand at 80 ka, the forest could have transgressed seaward as the sea-level receded. The forest could have grown continuously until return of sea level. However, north of Newport, the wave-cut platform identified with the last interglacial high stand (80 ka) now lies inland and at higher elevations than the platform on which stumps are rooted. The rooted stumps must have grown on a platform cut more recently than the last glacial high stand. Furthermore, surf zone regression by eustatic drop of sea level seems unlikely for the stumps in the range of 1.9–4.4 ka, because that is the period of late Holocene marine transgression (Berger, 1983).

Regression of the surf zone due to prograding sand features or other barriers cannot be ruled out for all sites studied; however, the Spencer Creek, Wade Creek, Coal Creek, and Moolack Creek stump fields are all in a sand-starved cell that is cut off from longshore sand supply by two major headlands (Peterson and others, 1991). Between Deer Creek and Grant Creek, the sites are on straight, broad, well-developed wave-cut platforms with wave-cut cliffs up to 10 m in height. Thus wave attack has been dominant at these sites in late Holocene time. China Creek and Blowout Creek lack well-developed wave-cut cliffs and uplifted wave-cut platforms, so sand barriers cannot be ruled out. Sunset Bay and Yachats River, because of their enclosed topography, are the most likely sites to have been isolated by sand bars.

There is abundant evidence that the Oregon coast is influenced by the tectonically active convergent margin of the Cascadia subduction zone (CSZ). Regional and/or local faults have vertically displaced the shoreline during strain buildup and coseismic release in late Holocene times (Darienzo and Peterson, 1990). Uplifted wave-cut platforms indicate the coastline has emerged at rates fast enough to cause regression of the surf zone (Ticknor, 1993; Mitchell and others, 1994).

The scarcity of surf zone forests discovered so far precludes a test of whether uplift of the forested wave-cut platforms was gradual or rapid.

Burial and preservation of the rooted stumps and forest soil

The presence of fresh forest litter in the surf zone and the abrupt upward termination of podzol profiles on ascending soil horizons implies rapid burial of the forest soil. Under normal forest soil conditions, aerobic fungi and bacteria decompose litter to form humus. The rate of decomposition is variable and depends on temperature, moisture, drainage, and the resin content of the litter. Typical residence time for deciduous leaves is 1–2 years (Waring and Schlesinger, 1985). Data are not available for rates of decomposition in temperate coniferous rain forests, but the presence of moss, leaves, and conifer needles with intact fine structure indicates that little decomposition occurred in the forest soil now preserved on the beaches. We propose that the forest soil must have been protected from agents of decomposition and fermentation within several years of deposition. Some stumps in the creek mouths are preserved in peat, but peat is absent from the wave-cut platforms. Conditions suitable for preservation of forest soil on the wave-cut platform can be produced by burial under (1) wet, salty beach sand; (2) arid dune sand; or (3) debris-flow deposits.

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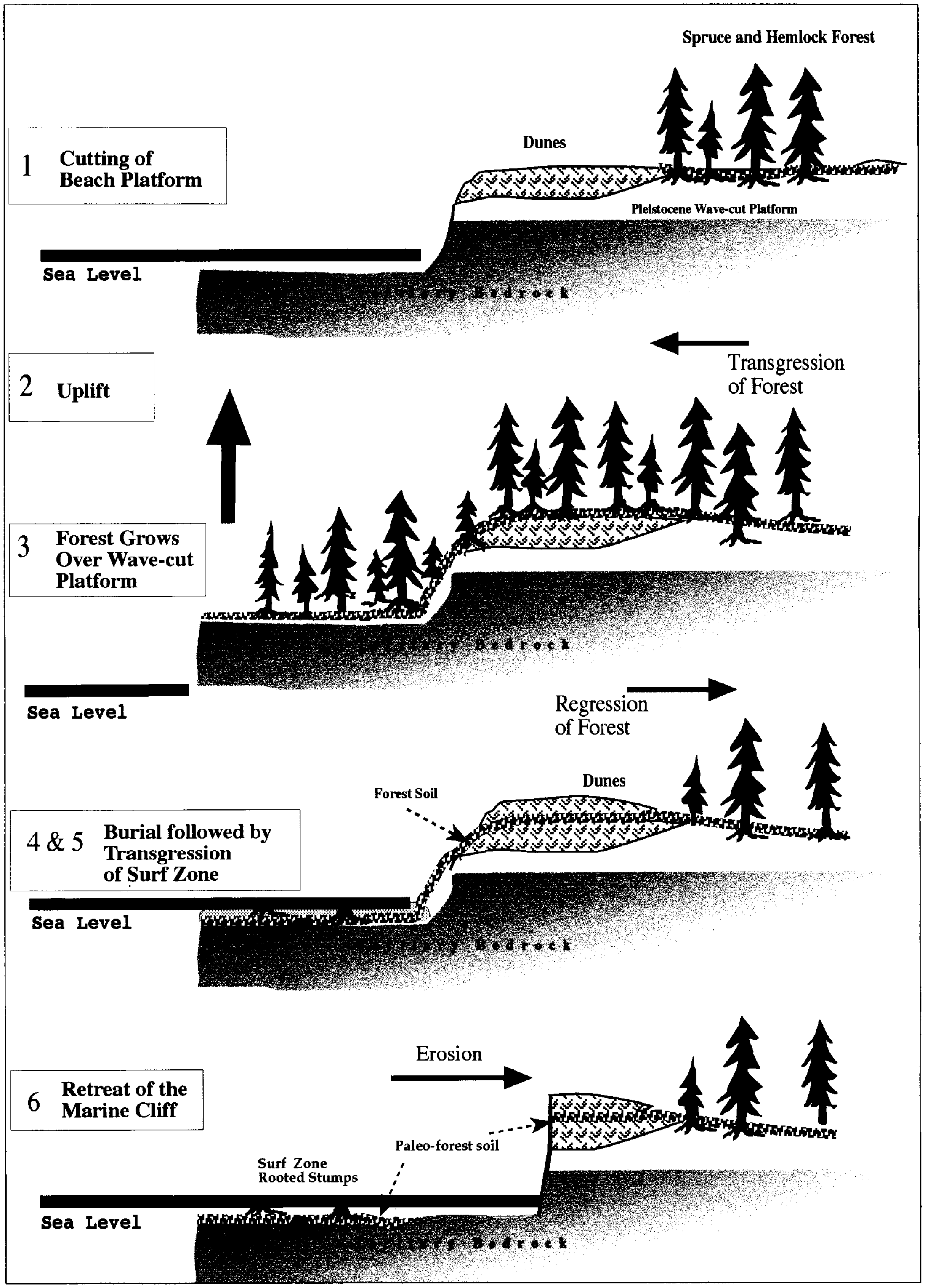

Figure 9. The six stages necessary to explain the occurrence of rooted stumps in the Oregon surf zone. Regression of the surf zone off the platform was probably the result of vertical tectonic displacement. Burial is inferred from the presence of nondecomposed forest litter. Transgression of the surf zone was not necessarily synchronous with burial and could have been the result of eustatic sea level rise, removal of sand barriers, or vertical tectonic displacement or any combination of the three.

(Continued from page 141)

Forest soil at Deer Creek appears buried in beach sand. Trees growing near beaches can be buried in wet, salty sand if there is a rapid seaward growth of the beach. Growth of the beach can be caused by an abrupt increase of littoral sand supply induced by shifting nearshore currents or by an increase in sediment supply to the littoral cell (Peterson and others, 1990). Sudden vertical tectonic displacement could also induce burial of trees in beach sand if the displacement is great enough.

The ascending forest soil horizons are covered by dune sand at China Creek and Blowout Creek. Rapid migration of dunes over the trees as a result of an abrupt increase in littoral sand supply is a possible agent for burial and protection of the forest. Vertical tectonic displacement could also induce migration of dunes over forests by introducing the forest to areas of active dune formation at lower elevations.

Debris flows cover forest soil at nine localities north of Thiel Creek. A nearly continuous apron 15 mi wide may have covered the beaches between Spencer Creek and Lost Creek and could have buried the forest on the beach platform. Although it is nearly impossible to determine whether or not debris flows are coseismic, debris flows are commonly associated with earthquakes. For example, over 10,000 debris flows occurred during the 1976 Guatemalan earthquake (M_s 7.5) (Harp and others, 1981).

Additional work is needed to verify whether deposits currently covering the forest soils reflect the initial burial of the forests.

Inundation of the forest

Inundation of the forest in the surf zone was not necessarily synchronous with burial. Preservation of litter by burial in beach sand or in a peat bog would have required a synchronous drop to sea level. However, burial by debris flows or eolian dunes could have taken place above sea level before inundation. At any rate, the forest was inundated by a transgressing surf zone that could have been the result of eustatic rise of sea level and/or removal of sand barriers and/or tectonic subsidence.

In this paper we do not attempt to discriminate between the possible mechanism of inundation. Possibly all are involved. For example, even though eustatic rise of sea level was a factor, it was less than 1 mm per year at 1.9–4.4 ka (Berger, 1983). Some parts of the coastline were tectonically uplifted faster than this. Others were probably tectonically submerging.

Sequence of events

Although we cannot assume the same sequence of events for all sites, we propose a six-step sequence (Figure 9) as the most likely one for the majority of sites of rooted stumps and associated forest soil. First, the wave-cut platform was cut at sea level prior to growth of the trees. Second, sea level regressed off the platform due to tectonic uplift. In the third stage, the forest grew over the platform. In the fourth stage, the forest was rapidly buried and the litter preserved. In the fifth stage, the forest was inundated by the surf zone. In the sixth and final stage, the forest soils and overlying deposits were eroded during the retreat of the marine cliffs.

CONCLUSIONS

The rooted stumps and forest soils on Oregon's beaches are remnants of forests similar to present-day coastal temperate rain forest that grew on the Holocene wave-cut platform and adjacent creeks, dune fields, and marine terraces. The paleo-forest soils exposed in the surf zone, in creek mouths, and on valley walls are probably contemporaneous with rooted stumps in the surf zone, but this cannot be established without further mapping, coring, and radiocarbon dating. The abrupt upward termination of the forest soil and the preservation of undecomposed litter indicates rapid burial by debris flows, dunes, or beach sands. The burial may have been coseismic and synchronous with inundation, but this cannot be established with the data set on hand. The preliminary ages of the stumps, 1.9–4.4 ka, show that the growth and burial of some of the trees took place after the time of major eustatic sea level rise in early mid-Holocene time. The rapid colonization and deterioration of the stumps and exposed soils in the surf zone indicate that these forest remnants were exposed only during short-lived erosion events or have not been previously exposed. The full cycle of platform cutting, uplift, forest growth, burial, inundation, and renewed platform cutting may have taken place over a period upward of 1,000 years. Additional platform-forest site coring/mapping and radiocarbon dating are necessary to test the extent, duration, and possible cyclicity of these processes. For example, do other forest remnants exist landward under Holocene dune fields or offshore on the inner shelf?

ACKNOWLEDGMENTS

Radiocarbon dating was supported by the Portland State University Department of Geology. This work was partially supported by grant No. NA36RG0451 from the National Oceanic and Atmospheric Administration to the Oregon State University Sea Grant College and by appropriations made by the Oregon State Legislature. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies. Author Hart is grateful to Ian Hart, Cathy Heflin, and Bob Shivers for their assistance in the field and to Cathy Heflin for her assistance in preparation of the manuscript and figures. The field work and manuscript benefited from discussions with Alan Niem and Paul Komar.

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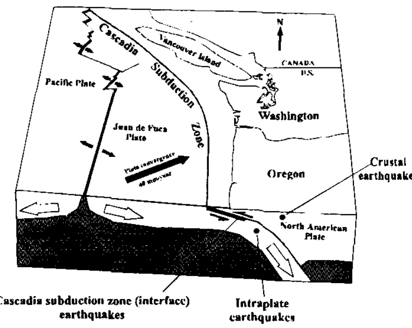
Waring, R.H., and Schlesinger, W.H., 1985, Forest ecosystems concepts and management: New York, N.Y., Academic Press, Inc. □

Winter term earthquake course offered by OSU on educational TV

A general-interest course entitled "Earthquakes of the Pacific Northwest" will be offered at Oregon State University on educational television during winter term, January-March 1998. The three-hour course will review the earthquake hazards from the Cascadia subduction zone (interface earthquakes), the overriding North American plate (crustal earthquakes), and the subducted Juan de Fuca plate (intraplate earthquakes). This is followed by discussions of earthquake forecasting, earthquake insurance, stability of buildings (including the effects of recent upgrading of the building code for seismic protection), and role of government agencies, including the Department of Geology and Mineral Industries. Included are also sections on retrofitting a typical Northwest residence and on preparing for the next earthquake. Speakers will include local experts from government and private industry.



The three-hour course is GEO 380, offered by educational television (EDNET) through Oregon State University. The course will be taught live in room ECE 102 on the OSU campus and on local Cable Channel 18 Monday evenings from 7 to 10 pm, starting January 5. Live satellite transmission will make the course available at the same time to students in Astoria (Clatsop Community College), Bend (Central Oregon Community College), Coos Bay (Southwestern Oregon Community College), Newport (Hatfield Marine Science Center), and Hood River (Memorial Hospital). The televised course will begin in the Portland area via tape delay on Monday, January 12, from 10 a.m. to 1 p.m. on Cable Channel 11. In southern Oregon, the course begins on Thursday, January 15, 7–10 p.m., and ends March 19, carried on Cable Channel 32.

The course satisfies the baccalaureate core curriculum requirement for a course relating science, technology, and society. The text will be the manuscript of a forthcoming book by the instructor, Dr. Robert Yeats. The book will be entitled *Earthquakes of the Pacific Northwest* and is to be published in 1988.

Interested persons can register for the three-credit course by phone at 1-800-235-6559. Additional information can be obtained from the instructor, Dr. Yeats, at 541-737-1226. □

Schnitzer named national Outstanding Reclamationist of the Year for environmental work

E. Frank Schnitzer of the Oregon Department of Geology and Mineral Industries (DOGAMI) has been named 1997 Outstanding Reclamationist of the Year by the National Association of State Land Reclamationists (NASLR).

Schnitzer, 45, a lead scientist for the DOGAMI Mined Land Reclamation (MLR) Program in Albany, received the award on September 16 during the NASLR joint annual meeting with the Interstate Mining Compact Commission in Lake Placid, New York.

E. Frank Schnitzer

NASLR, the nationally recognized authority on the reclamation of mined land, advocates research, innovative technology, and training in restoring lands and waters affected by mining. Oregon's reclamation program ensures that mined land is "reclaimed" for subsequent agricultural, forestry and other beneficial uses.

NASLR President Bruce Ragon recognized Schnitzer's years of work and dedication to the science of reclamation. "This award is not given every year, but Frank's ability to find technical solutions to complex issues is outstanding," said Ragon, also noting his role in creating guidelines for floodplain operations to protect fisheries and his quick response to the Oregon floods of 1996 and 1997, when Schnitzer organized an interagency team of experts to help mining operators with flood control.

"I'm always pleased when outstanding Oregon public servants are recognized for their talent and hard work," said Governor John Kitzhaber. "I congratulate Frank Schnitzer on this award and thank him for his dedication to his job and the state as a whole."

In addition to inspecting and permitting aggregate mines in Oregon's northwest region, Schnitzer has statewide responsibilities for trouble-shooting and inspecting the most complex and controversial of the 800 permitted mines in Oregon.

"Frank's field savvy and technical knowledge have earned him much respect in the aggregate industry," said MLR Supervisor Gary Lynch. "His negotiation skills have saved the industry—and the State of Oregon—a lot of time and money in turning rock quarries back to a natural environment, while helping operators find cost-effective ways to meet or exceed Oregon's mining standards."

Schnitzer also led DOGAMI field efforts to help implement the Oregon Coastal Salmon Restoration Initiative (later named "The Oregon Plan"). Last year, he and other MLR reclamationists inspected *all* aggregate mines near the coast, with operators given "fish report cards" on the water quality of their operations. With flood issues emerging as a priority after the 1996 and 1997 storms, Schnitzer is helping DOGAMI and other state and federal agencies create the first agreement among major aggregate producers near the Willamette and McKenzie Rivers to coordinate reclamation efforts.

"Frank has been a big help to our industry over the years he has been with DOGAMI," said Rich Angstrom, managing director of the Oregon Concrete and Aggregate Producers Association. "Some of the strides we have made in meeting regulatory requirements would not have been possible without him."

Schnitzer, with DOGAMI since 1983, received his bachelor's degree in soil science in 1978 from California Polytechnic State University and his master's degree in soil science and biometeorology in 1980 from Utah State University. He lives in Lacomb near Lebanon, Oregon.

"This award belongs to the whole Albany office because we work as a team," Schnitzer said. "We're in this profession because we care about Oregon's environment and about doing the right thing. So recognition like this becomes important—like cash for the psyche." □

Zhenming Wang joins DOGAMI earthquake team

The Oregon Department of Geology and Mineral Industries (DOGAMI) has acquired the services of Zhenming Wang, who joined the Department's earthquake staff as a Geotechnical Specialist.

Zhenming Wang

Wang comes to DOGAMI from the University of Kentucky, where he was research assistant, student, and consultant, mostly in the Department of Geological Sciences but also with other branches of the university.

Wang began his training and his professional career in China, where he earned his first bachelor's degree in geology at Peking University in Beijing and worked as a geologist, geophysicist, and geotechnical engineer in Fujian Province.

At the University of Kentucky he acquired, in order, a master of science degree in geophysics, a bachelor's degree in civil engineering, and his doctorate in geophysics and is about to receive a master of science degree in environmental engineering. Since 1987, he has been making numerous published contributions to research in geology, geophysics, and engineering, particularly in the area of earthquake hazards.

As a member of the DOGAMI earthquake team, Wang participates in all aspects of earthquake hazard mitigation. "His broad technical experience," says team leader Mei Mei Wang, "is most welcome for the many tasks the Department is undertaking to reduce the risks for Oregonians of living in earthquake country." □

DOGAMI PUBLICATIONS

Released September 30, 1997

Earthquakes—Converging on Cascadia, Symposium Proceedings, Association of Engineering Geologists 40th annual meeting, September 30 to October 4, 1997, Portland, Oregon, edited by Yumei Wang and Klaus K.E. Neuendorf. Special Paper 28, 96 p., $12.

The Oregon Department of Geology and Mineral Industries (DOGAMI) and the Association of Engineering Geologists (AEG) have jointly released the proceedings of a symposium on earthquakes in the Pacific Northwest, one of several special events of the AEG annual meeting 1997. The proceedings have also been published as AEG Special Publication 10.

Focus of the symposium was to broaden the understanding of earthquake research issues centering on the Cascadia region earthquake setting and to apply them to hazard risk reduction. Keynote speaker for the symposium was Bruce A. Bolt of the University of California at Berkeley, who presented an "Assessment of seismic hazard assessments." Other contributors included researchers from the U.S. Geological Survey, DOGAMI, Oregon State University, and the firm of Woodward-Clyde Federal Services and a private earthquake engineering consultant. □

Entertaining mug teaches about tsunami hazard

In conjunction with World Disaster Reduction Day on October 8, 1997, a cooperative federal/state partnership has created a special gift that carries the tsunami safety message in a non-alarmist, playful manner. It is a heat-sensitive mug that, when cold, depicts a person splashing in the ocean and the heading "Tsunami?" When the mug is hot, the picture changes to the tsunami logo, the official tsunami hazard symbol for Oregon, Washington, California, Alaska, and Hawaii, and the heading changes to "TSUNAMI!" The other side of the mug shows—hot or cold—a permanent checklist of the essential steps to escape a tsunami. It also includes the web-site address for the National Tsunami Hazard Mitigation Program so that those interested can use their computer to find further information about this natural hazard.

The mugs are now available at the Hatfield Marine Science Center in Newport, the Alsea Bay Bridge Interpretive Center in Waldport, and the Nature of the Northwest Information Center in Portland. Additional coastal retail facilities (gift shops) will also be carrying the tsunami mug in the near future. Suggested retail price of the mug is $12.00. Further information is available from Jessica Waddell at 541-867-0274 or the Nature of the Northwest Information Center at 503-872-2750. □

THESIS ABSTRACTS

The Oregon Department of Geology and Mineral Industries 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 Petrologic Evolution of the Silicic to Intermediate Volcanic Rocks underneath Steens Mountain Basalt; SE Oregon, by Vera W. Langer (M.S., Oregon State University, 1991), 109 p.

Steens Mountain in southeast Oregon is part of the northern Basin and Range province, and represents a horst tilted about 10° to the west that is bounded to the east by a high-angle, north-northeast-trending normal fault. The minimum displacement is about 1,200 m. Volcanic rocks, exposed along the eastern escarpment, range from basalt to high-silica rhyolite. By establishing a stratigraphy and determining chemical variations in the volcanic rock sequence underlying the Steens Mountain Basalt, it was possible to evaluate the origin of this volcanism and the role of crustal contamination, explain its chemical variation with time, and relate the chemical evolution to extensional processes. The necessary chemical data were obtained by X-ray fluorescence, electron microprobe, and instrumental neutron activation analyses; field mapping provided information about stratigraphy and structure.

The oldest units are lake sediments, which are overlain by a volcanic rock sequence that proceeded from early rhyolitic tuffs to rhyolitic lava flows, dacites, and andesites, and culminated with the eruption of Steens Mountain Basalt (SMB). All stratigraphic units are tilted to the norhtwest or southwest to various degrees. Early sediments and rhyolitic tuffs are tilted as much as 25°; whereas younger andesites (15° tilt), and SMB (5–10° tilt) overlie the older units unconformably. The stratigraphy and mapped unconformities indicate that active, volcanic episodes alternated with episodes of erosion and block tilting. Tilting events are thought to be connected to extensional tectonics, and the maximum extension for the Steens Mountain area is estimated to be 30 percent.

Relationships between basalt, andesites, dacites, and rhyolites of the Steens Mountain volcanic suite are complex. Crystal fractionation alone cannot relate the different rocks to each other. Trace-element chemistry of intermediate compositions requires fractional crystallization plus large degrees of assimilation and magma mixing. Magma mixing is also suggested by different plagioclase populations and zoning patterns in plagioclase and clinopyroxene phenocrysts from intermediate rock compositions. The role of assimilation is greater in the andesites and that of mixing in the dacites. The silicic mixing partner has to be extremely low in rare-earth elements. Rhyolites are not directly related to the rest of the suite, but are related to each other by crystal fractionation. They most likely evolved from a partial melt of depleted crust (probably lower crust) by fractionation.

Assimilation coupled with fractionation and simple magma mixing are typical magma processes for major metaluminous volcanic suites in the Basin and Range and elsewhere. These processes decrease the density of stagnated basaltic melts and subsequently increase their buoyancy. Extension triggers the ascent of mafic magma, but small amounts of extension alone do not increase the mean crustal density enough for basalts to rise to the surface. Increasing the crustal density by injection of mafic plutons and extension is able to produce a shift in volcanism from intermediate to more basaltic compositions as seen at Steens Mountain, where the influence of crustal material decreases upwards in the volcanic sequence.

Potential for coastal flooding due to coseismic subsidence in the central Cascadia margin, by Elson T. Barnett (M.S., Portland State University, 1997), 144 p.

Interpretations made from compilation of existing core and cutbank data for Oregon and Washington are used to evaluate the potential flooding impact from regional coseismic subsidence.

Estimates of regional subsidence are based on tidal level indicators including plant macrofossils, peat development, and diatoms. A compilation of existing late Holocene stratigraphic records shows multiple burial events in all bays of Oregon, however some coastal sites in central Oregon show continuous submergence. Tests of tidal level indicators using modern Cascadia wetlands indicate that paleosubsidence can be estimated to 0.0±0.5 m, 1.0±0.5 m, and 2±0.5 m. An AMS date from a cone atop a buried wetland deposit (250±40 RCYBP) in Tillamook Bay, Oregon, is consistent with the interpretation of the most recent buried wetland deposit correlated to a regional coseismic subsidence event occurring at ~A.D. 1700. Estimates of paleosubsidence produced by the most recent regional seismic event are 1 to 2 m ±0.5 m for Grays Harbor, 1±0.5 m Necanicum Estuary, 1±0.5 m Tillamook Bay, and 0 to 1 m ±0.5 m Siletz Bay. A database using the most recently buried wetland is produced from published and unpublished core and cutbank data collected throughout the central Cascadia margin. A regional trend of decreasing subsidence is found from north to south and locally from east to west. These trends yield an apparent correlation between the amount of subsidence and distance (east-west) from the subsidence site to the Cascadia trench.

Paleosubsidence estimates for sites at Elliot Slough (2.0 m) and Neawanna Creek (1.0 m) are used for analysis of flooding in Aberdeen, Washington, and

Seaside, Oregon, respectively. Paleosubsidence estimates added to the 10- and 100-yr. flood elevations are compared to current 10-, 100-, and 500-yr. flood elevations (pre-subsidence). Emergency access roads, dikes, tidegates, and city drainage outfalls are susceptible to seasonal flooding at 1- to 10-yr. flooding frequencies following coseismic subsidence of 1–2 m.

Volcanology and petrology of the Rattlesnake Ash-Flow Tuff, eastern Oregon, by Martin J. Streck (Ph.D., Oregon State University, 1994), 185 p., 1 data diskette.

The dissertation consists of three chapters of which each is designed as a separate publication. The author of the thesis is the first author of the first two papers (chapters I and II) and is the only author of the last paper (chapter III).

Chapter I. Facies variations in a thin, widespread ignimbrite sheet: The Rattlesnake Tuff, eastern Oregon, by Martin J. Streck and Anita L. Grunder.

Today's outcrops of the Rattlesnake Ash Flow Tuff, emplaced 7.05 m.y. ago, cover ca. 9,000 km^2, but reconstructed original coverage was between 30,000 and 40,000 km^2. Thicknesses are remarkably uniform, ranging between 15 and 30 m for the most complete sections. Only 13 percent of the outcrop area is covered with tuff thicker than 30 m, up to a maximum of 70 m. Present-day estimated tuff volume is 130 km^3, and reconstructed erupted magma volume is 280 km^3 dense rock equivalent (DRE). An exponential decrease in average pumice size implies a source area in the western Harney basin, centered on the main outcrop areas. Distance from inferred source to most distal outcrops is 150 km. A large number of welding and crystallization zones formed during post-emplacement processes. The zone of partial welding, the vapor phase zone, and the lithophysal zone are divided into macroscopically distinguishable subzones. Rheomorphic vitric to devitrified tuff is found up to a radius of 40–60 km around the inferred source. In non-rheomorphic tuff, lithological zoning of individual sections, at constant outcrop thickness of 17–23 m, varies from vitric, non-- to incipiently welded tuff throughout to highly zoned sections consisting of a basal non- to densely welded vitric tuff overlain by a zone of crystallized tuff which grades internally from spherulite to lithophysae-dominated, to a zone of devitrification, and finally to a zone of vapor-phase crystallization and is capped by upper partially welded vitric tuff. The two facies zonation extremes occur within 1–3 km of one another at several places. Welding and crystallization decrease with distance from the inferred source, but the regional pattern becomes apparent only by integrating many sections within a given area. Strong local variations are interpreted to be the result of theshold-governed welding and crystallization near the critical welding temperature, due to slight original thickness differences influencing the thermal insulation. A three-dimensional welding and crystallization facies model has been developed based on 85 measured sections incorporating local and regional variations.

Chapter II. The Rattlesnake Tuff, part I: Relationships between high-silica rhyolites, dacites and mafic inclusions, by Martin J. Streck and Anita L. Grunder.

The Rattlesnake Ash Flow Tuff from eastern Oregon represents ca. 280 km^3 of high-silica rhyolite magma erupted as pumices and glass shards. Dacite pumices make up less than 1 percent of the total volume, and quenched basalt and basaltic andesite inclusions inside dacite pumices constitute $<<0.1$ volume percent.

Trace and major element variations among high-silica rhyolite pumices indicate a series of progressively more evolved compositions. Derivation of least evolved high-silica rhyolites through dehydration melting events is the process that is most compatible with the chemical record. Major element composition of least evolved Rattlesnake Tuff high-silica rhyolites and melts obtained from dehydration experiments are similar. Ba/Rb ratios of 30 ± 5 and La_NYb_N of 4.5 ± 0.2 for the group of least evolved high-silica rhyolites (group E pumices) constrain potential protolith compositions to some amphibolites, high-Ba greywackes or granulite facies intermediate to mafic rocks.

At least three types of mafic inclusions, ranging in size from cm to mm, are recognized which are mainly found inside dacite or dacite/rhyolite banded pumices. Ubiquitous glomerocrysts of plagioclase and chrysolite characterize the inclusion type which is similar to regional high-alumina olivine tholeiite (HOAT) lava flows typical of the Oregon Plateau. Phenocrysts and goundmass show strong quenching features. Phenocryst-poor, basaltic andesite inclusions with a micro-quenched groundmass is the second type. Such inclusions have round to streaky forms, often with mingled textures with the host pumice. Phenocryst-poor inclusions acquired their enriched trace element signatures mainly through fractionation and recharge processes. The third inclusion type is also basaltic but consists of clinopyroxene which poikilitically encloses plagioclase phenocrysts or of granular olivine with plagioclase.

Dacite pumices (62-68 weight percent SiO_2) are phenocryst poor with 1–4 percent crystals. Mineral assemblages are strongly bimodal with euhedral, resorbed, or reacted phenocrysts from high-silica rhyolites or from basaltic magmas. Dacite magmas are likely to have been generated through mixing of least evolved high-silica rhyolites with enriched basaltic andesite magma represented in phenocryst-poor basaltic andesite inclusions. A silica gap of ca. 6 weight percent exists between dacites and high-silica rhyolites. Only pumices with strong banding fall in the gap.

The reconstructed magma chamber was stratified from high-silica rhyolites at the top to mafic magmas with dacites at the interface. The compositional range of the pre-eruption magma chamber is based on banded pumices containing all compositions. The stratification is inferred from vertical and lateral distribution of erupted compositions within the Rattlesnake Tuff. This stratification is likely to have been stable over some time, based on a petrologic model, which explains the relationships between high-silica rhyolites, dacites, and basaltic compositions. After formation, a silicic magma chamber impedes the ascent of mafic magmas (HAOT), therefore causing the mafic magma to fractionate (enriched mafic inclusions), which in turn thermally stabilizes the silicic magma, causing it to fracionate (zoned high-silica rhyolites). Mafic and silicic melts interact and form dacites along their interface.

Chapter III. The Rattlesnake Tuff, part II: Differentiation of the high-silica rhyolites, by Martin J. Streck.

More than 99 percent of the 280 km^3 of magma erupted as Rattlesnake Ash-Flow Tuff, eastern Oregon, is composed of high-silica rhyolite in form of glass shards and pumices. Glassy, high-silica rhyolite pumices cluster in five chemical groups, three consisting of white pumices and two consisting of dark-gray pumices. Key elements for defining these five high-silica rhyolite compositions are Fe, Ti, La (LREE), Ba, Eu, Rb, Cs, Zr(Hf), Ta(Nb), and Th. On element-element diagrams, the high-silica rhyolite pumice clusters define linear or curvilinear arrays sometimes with gaps between groups. Heavy liquid separation on one representative pumice from each group indicates crystal contents around 1 weight percent for the least evolved composition decreasing to 0.09 weight percent and to virtually aphyric at the most evolved composition. Progressive changes with higher degree of evolution of the magma occur in mineral modality, mineral chemistry, and partition coefficients. Data on physical parameters indicate that conditions became more oxidizing with differentiation.

Models of crystal fractionation in non-modal proportions of observed phases with empirical partition coefficients agree generally with enrichment trends and yield compositions of removed solids ranging from syenitic to granitic. On the other hand, crystal fractionation of observed phases in modal proportions is incompatible with observed zonation patterns. Fractionation combined with assimilation (AFC) could have occurred during the first 20 percent (of 60 percent) fractionation but is thought to be of minor importance for observed chemical gradients among high-silica rhyolites. Accumulation of liquids in a single stratified chamber generated by successive partial melting is inconsistent with extremely low Ba (25 ppm) in most evolved and highest Ba (1900 ppm) in least evolved rhyolite. Derivation of the intermediate high-silica rhyolite compositions through mixing of end members is excluded because variable mixing degrees are necessary to explain element abundances of individual pumices.

The likeliest process responsible for the generation of the progressively more evolved high-silica rhyolite compositions is a differentiation process through which each composition is derived from the previous, less evolved liquid. Assuming a slablike chamber geometry, the fractionation process might occur primarily along the roof of the chamber, which is the coolest and largest surface. Each successive more evolved and lighter liquid is generated at the roof and stays as the top layer, generating a composition- and density-stratified magma chamber.

Geologic evidence of historic and prehistoric tsunami inundation at Seaside, Oregon, by Brooke K. Fiedorowicz (M.S., Portland State University, 1997), 197 p.

Over the past decade research conducted along the Cascadia subduction zone coast established evidence for coseismic subsidence, liquefaction, and nearfield tsunami deposition. Seaside is a low-lying northern Oregon coastal city, potentially at risk for nearfield tsunami inundation from a Cascadia earthquake. The 1964 Alaskan farfield tsunami impacted Seaside, and deposits from that event serve as a model for interpreting prehistoric tsunami deposits in the Seaside area.

A reconnaissance subsurface study of potential tsunami inundation sites was performed by trenching and gouge coring in the coastal wetlands along the Necanicum River, Neacoxie Creek, drainage to the east of Neacoxie Creek, Stanley Lake, and Neawanna Creek. A total of 278 core sites were logged for shallow lithologic stratigraphy and contact relations.

To establish tsunami depositional trends from the 1964 farfield event, 71 observation sites, 62 core logs, two grids, and 8 trenches were evaluated. Wave amplification occurred in the Necanicum River/estuary mouth and north of 12th Avenue, south of the G Street bridge crossing Neacoxie Creek, and south of the Hwy 101 bridge crossing Neawanna Creek. These areas contain anomalously thick sand deposits compared to the deposits along the Necanicum River and Neawanna Creek where the wave attenuated, depositing a sand layer thinning upstream.

Neawanna Creek wetlands contain most of the preserved A.D. 1700 earthquake subsidence horizons and sand layers. Within the Seaside wetlands, 90 core sites contain the A.D. 1700 subsidence horizon. No subsided peaty horizons were observed west of Neawanna Creek. At the Mill Creek/Stanley lake area, the A.D. 1700 tsunami deposition is minimal to nonexistent. In the southernmost Neawanna wetlands, A.D. 1700 tsunami deposits are restricted to a narrow zone southeast of the Mill Ponds and north of the S Avenue bridge.

Overland inundation of the A.D. 1700 tsunami, interpreted from core records, did not reach the central Neawanna wetlands (<1,5 km east of the present coastline) and crossed a narrow cobble ridge entering the Neawanna wetlands from a southern Necanicum channel. □

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